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Establishment of an Interdisciplinary Project to Evaluate Ecological Implications of Climate Change in Dry South Coast Forest Ecosystems

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086

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H. Klassen, S.C. Saunders, J.M. Kranabetter,
A. MacKinnon, H. Griesbauer, and O. Fitzpatrick

BRITISH COLUMBIA

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Prepared by
Heather Klassen and Sari C. Saunders
B.C. Ministry of Forests, Lands and Natural Resource Operations
2100 Labieux Road, Nanaimo, BC V9T 6E9
Heather.A.Klassen@gov.bc.ca
Sari.Saunders@gov.bc.ca

Marty Kranabetter and Andy MacKinnon
B.C. Ministry of Forests, Lands and Natural Resource Operations
PO Box 9536, Stn Prov Govt, Victoria, BC V8W 9C4
Marty.Kranabetter@gov.bc.ca
Andy.MacKinnon@gov.bc.ca

Hardy Griesbauer
College of New Caledonia
Applied Research and Innovation
3330–22nd Ave., Prince George, BC V2N 1P6
griesbauerh1@cnc.bc.ca

Owen Fitzpatrick
University of Victoria
School of Environmental Studies
Turpin B243, 3800 Finnerty Road, Victoria, BC V8P 5C2
owenfitz@uvic.ca

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Climate change is anticipated to alter the species composition, distribution, and productivity of forest ecosystems. In 2010, we established a research project to evaluate ecological attributes of sites with different relative soil moisture and nutrient (site) conditions and subregional climates. The project focussed on dry south coast forests of British Columbia, including the Coastal Douglas-fir moist maritime (CDFmm) and Coastal Western Hemlock very dry maritime (CWHxm) Biogeoclimatic Ecosystem Classification (BEC) subzones on southeast Vancouver Island. This research is directed toward refining and quantifying a conceptual model of ecosystem function across spatial scales, establishing hypotheses regarding ecosystem change with projected climate shift, and identifying effective field indicators of climate change and its impacts on structure, species composition, and function in these forests.

We initially developed a set of hypotheses regarding key drivers of current ecosystem function in the CDFmm landscape and the relationships by which climate affects species composition and structural attributes in these forests. We then established a set of field subprojects and selected study variables that would indicate and integrate these relationships to climate, would allow us to quantify our model of ecosystem processes in the CDFmm, and would be practical indicators of shift in function of the CDFmm with climate change. The subprojects focussed on microclimate, tree growth, decomposition rates of fine woody material, salal productivity, and ecosystem nitrogen status, and the interrelationships among these variables. The effects of climate on the study variables were examined at three spatial scales: landscape (study region), subregion (north, central, and south latitudinal transects), and site (CDFmm xeric, CDFmm zonal [mesic], CDFmm hygric, CDFmm–CWHxm transition zonal, and CWHxm zonal plots within each subregional transect).

The initial findings of each subproject quantified current conditions across the study region and among sites types of the BEC subzones. Structural stage ranged from young (distinct canopy layers) to old (complex, multi-storeyed structure). The mesic sites had the greatest number of pieces of coarse woody debris (CWD)($\bar{x}$ = 12 [± 6.1 SD] pieces per site), the hygric sites had the most diversity in CWD species (three to five species per site), and the xeric sites had the fewest number of pieces of CWD (one to four pieces per site) and the lowest diversity of CWD species (one to two species per site). The xeric sites had the smallest mean tree diameter and tree heights (47.4 cm and 24.3 m, respectively), while the hygric sites had the largest (88.7 cm and 45.4 m, respectively). Douglas-fir was present in the forest canopy on all sites.

Mean annual temperature on the south transect CDFmm mesic (forested) site was 0.5°C lower than that at the Victoria climate station (open) site, although variation around the means of these two locations was similar. Growing-season conditions differed between the CDFmm and CWHxm. The dry season commenced in May in the CDFmm and

continued until the end of September but began in early June in the CWHxm and continued until late August. Mean annual precipitation was higher in the CWHxm (886 mm) than in the CDFmm (657 mm), which resulted in a longer wet season. Subregionally, mean daily temperature on the north transect was higher (9.5°C) than that on the central (8.7°C) and south (8.9°C) transects; mean daily soil moisture on the south and north transects (12.9% for both sites) was less than that on the central transect (13.7%). The south and central transects had lower mean annual precipitation (692 and 650 mm, respectively) than the north transect (825 mm), while the south transect had higher mean annual solar radiation (380.7 w/m^2) than the central (260.6 w/m^2) and north (200.5 w/m^2) transects. At the site level, the xeric sites had the warmest air temperatures (11.1°C); the hygric sites had the coolest (8.0°C). Generally, mean soil moisture was highest (18.0%) on the hygric sites in the CDFmm, and was highest on the CWHxm sites (10.8%) among zonal sites.

Analyses illustrated some consistencies and differences in climate influences on ecosystem attributes among subregions (transects) of the study area and among site types. In the CDFmm, decomposition rate increased from xeric to hygric sites, and there was a strong, negative relationship of decomposition of fine woody material to annual soil temperature across subregional climates ($r = -0.91$). Similarly, variations in soil nitrogen across site types had a significant effect on tree site index (a forest productivity indicator) and on the nitrogen content of the wood of live trees. However, xeric sites were outliers in the (otherwise strong, positive) relationship between fall soil moisture and decomposition ($r = 0.90$ excluding xeric sites). Douglas-fir growth was also distinctive on the xeric plots: it was associated with the high variability in soil moisture at these sites. At the subregional scale, there was a notable decline in annual tree growth (-48.4% [± 4.8 SE]) on all sites on the south transect over the last three decades. This trend was less clear in the central and north samples, illustrating the interactions of climate effects at the subregional and site levels.

This research project will be continued in order to parameterize relationships of climatic and site conditions to ecosystem features and to predict potential shifts in forest composition and structure with climate change. Analyses presented in this report form the basis of experimental work to test the soundness of new quantitative models of ecosystem processes in the CDFmm and to assess the utility of attributes proposed for use in field detection of changes in these ecosystems. Field monitoring and experimental work will be integrated with projections from dynamic vegetation models to guide forest management and conservation activities within the CDFmm–CWHxm. The project infrastructure and baseline data are available for additional, related research.

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1 INTRODUCTION

There is increasing evidence that global climate change will have an impact on the distribution and nature of forested ecosystems. Direct impacts on physiology of plants, resulting in changes in recruitment, growth, reproduction, and mortality, and indirect effects on external factors, such as disturbance regimes, will alter species ranges and interspecific dynamics (Dale et al. 2001; Hansen et al. 2001). In the 20th century, mean annual temperature and mean annual precipitation in the Pacific Northwest increased by 0.91°C and 178 mm, respectively (Mote 2003). Winter and summer temperatures increased more than spring and fall temperatures, and winter and spring precipitation increased more than summer and fall precipitation (Mote 2003). Climate modelling at regional extents and finer resolutions reflects the effects of complex or extreme topography (Randin et al. 2009) and maritime influence. For example, analyses for the southwest coast of British Columbia and the U.S. Pacific Northwest suggest that increases in winter precipitation (0.5–1.0 mm/day) and in the length and intensity of the summer drought season could be expected (Salathé et al. 2008; Spies et al. 2010).

In British Columbia, the Biogeoclimatic Ecosystem Classification (BEC) (Pojar et al. 1987) system is used to classify and map ecosystems across spatial scales. Ecological subzones are defined and delineated by the dominant potential vegetation that is supported on zonal[1] sites under a given climatic regime.[2] Currently, the southeast coast of Vancouver Island is mapped as the Coastal Douglas-fir moist maritime (CDFmm) and Coastal Western Hemlock very dry maritime (CWHxm) subzones (Green and Klinka 1994) (Figure 1) at low elevations. Climate change projections indicate that over the next several decades, climate conditions that are suitable for the CDFmm will shift about 10 km northward and about 128 m up in elevation into areas that are now classified as the CWHxm (Hamann and Wang 2006; Wang et al. 2012a). Projected reductions in water availability in the summer could limit growth rates of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*), the dominant overstorey tree species, and affect vigour of other vegetation across site types (Burton and Cumming 1995; Cumming and Burton 1996; Spittlehouse 2003; Rehfeldt et al. 2006).

1 The plant community is influenced primarily by climate (versus topographic or edaphic factors).

2 BEC Web: www.for.gov.bc.ca/hre/becweb.

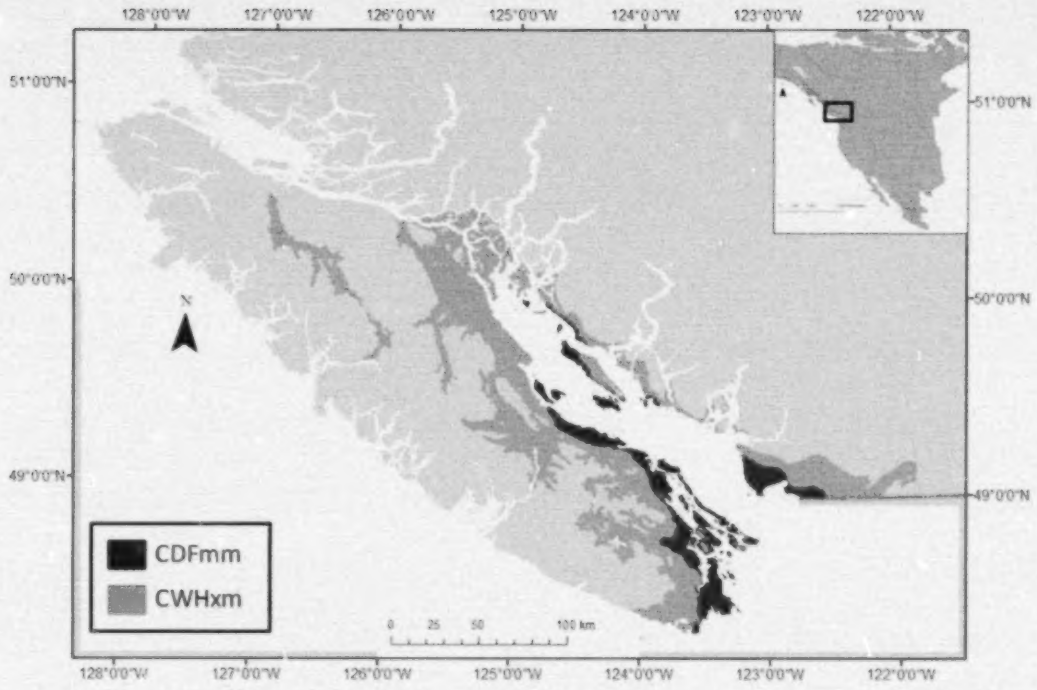

FIGURE 1 *Current distribution of the CDFmm and CWHxm biogeoclimatic subzones on southeastern Vancouver Island, the Gulf Islands, and adjacent mainland coast, British Columbia (BC MOFR 2011). Inset figure of North America with study area highlighted in black box.*

In 2010, we established the Dry South Coast Ecosystems Climate Change Project (hereafter the project), to investigate the potential impacts of climate change on ecosystem attributes and processes, including microclimate, decomposition, vegetation productivity and regeneration, and nutrient turnover and uptake. The project was designed to describe variability in key ecosystem processes across the CDFmm and CWHxm subzones and across site conditions within the CDFmm. We quantified ecological attributes and relationships on zonal (mesic) sites across the transition from the CDFmm to the CWHxm, and at xeric, mesic, and hygric sites within the CDFmm.

The project began as a case study within a multi-landscape study of operational indicators of ecosystem resilience that was initiated through the Future Forest Ecosystems Initiative (FFEI) (BC MOFR 2006). In part, the FFEI proposed that British Columbia's forest and range management framework should incorporate concepts of ecological resilience theory (Gunderson and Holling 2002; Walker et al. 2004), which can offer valuable insight into the complexities and nonlinearities of ecosystem dynamics. It was expected that this management approach would help achieve long-term sustainability of landscape function and resource use in a time of rapid ecological change imposed by both resource extraction pressures and climate shift (Campbell et al. 2009).

Although ecological resilience theory can enhance the understanding of drivers and mechanisms of ecosystem function and ecosystem responses to change, its multi-scaled, non-linear approach to problem-solving can be challenging to implement in management and operational settings (e.g., forest harvest planning, species-at-risk conservation). We initiated the development of a framework within which operational measures of ecological resilience could be assessed for the CDFmm–CWHxm system. A conceptual model (e.g., Peterson et al. 2003; Nitschke and Innes 2008) was developed to generate null hypotheses about mechanistic relationships that drive current (or recent historic) ecosystem structure, composition, and function (Figure 2). Preliminary literature review and conceptual mapping, and subsequent work by Klassen (2012), identified specific climatic variables and historic and current disturbance regimes as key drivers of the CDFmm–CWHxm landscape. This conceptual framework assisted in identifying variables that may be effective operational indicators of ecological resilience or shift within these dry south coast ecosystems. Subprojects were developed to evaluate focal response variables that can be used to study the implications of management, including restoration, on resilience of this landscape in the context of climate change.

Although the CDFmm subzone represents a small proportion of British Columbia (<0.3% of the province), it is of particular interest and concern due to increased development pressure, the limited amount of provincial Crown land (80% of the subzone is private[3]) (Table 1), and the high number of red-

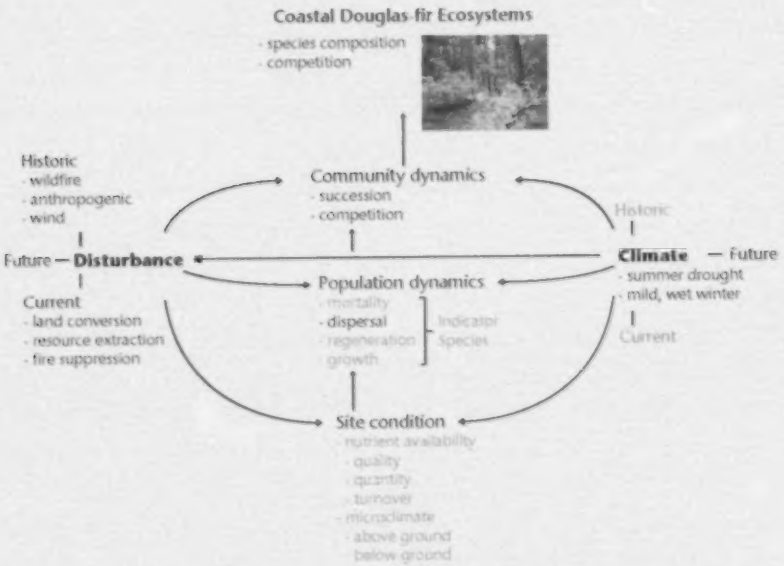

FIGURE 2 *Conceptual model of the mechanistic relationships that drive current (or recent historic) ecosystem structure, composition, and function in the CDFmm–CWHxm study area. Key drivers of current condition are shown in bold. Components of the conceptual model currently being investigated within the Dry South Coast Ecosystems Climate Change Project are shown in red.*

3 Private land excludes municipal, provincial, and federal land.

TABLE 1 *Land ownership in the CDFmm and CWHxm subzones (BC LRDW 2011)*

Land area	CDFmm km² (%)	CWHxm km² (%)
Total area	2520	9583
Private land	2016 (80)	5270 (55)
Public land[a]	504 (20)	4313 (45)

a Includes municipal, provincial, and federal land.

(extirpated, endangered) and blue- (threatened) listed ecological communities and species (46 communities, 291 species of wildlife and plants, including freshwater and saltwater species [BC CDC 2013]) in the subzone. The modified Mediterranean climate of the CDFmm supports plant communities with analogues to the south, in the U.S. Pacific Northwest (e.g., Puget Sound, southwest Oregon, San Juan Islands) (Franklin and Dyrness 1973; Nuszdorfer et al. 1991).

Though only 8.3% of the CDFmm is within the timber harvesting land base,[4] most of the subzone has been logged in the past 100 years, and older forests (>250 years) now cover only approximately 610 ha of the CDFmm land area (Madrone 2008[5]). More than 30% of the land area in the CDFmm has been converted to urban, rural, agricultural, and industrial use (Madrone 2008). Population expansion within the subzone is a primary source of habitat loss, fragmentation, and degradation. In current provincial linework, the CDFmm is mapped to a maximum elevation of 150 m; however, Terrestrial Ecosystem Mapping (TEM) of the subzone (Madrone 2008) suggests that it may be appropriate to raise the elevation to 380 m on the Saanich Peninsula and north along Vancouver Island to the Cowichan Valley. Work summarized by Erickson and Meidinger (2007) indicates that the CDFmm may occur at elevations > 400 m, as evidenced by the presence of Garry oak communities within the southern portion of this geographic range.[6]

The adjacent CWHxm (divided into the eastern xm1 variant and the western xm2 variant) has a less pronounced summer moisture deficit, as currently characterized, and is generally cooler and wetter than the CDFmm. The CWHxm also has a larger proportion of public land (45% of the subzone) than does the CDFmm (20% of the subzone). Although the CWHxm comprises only 1.0% of province, it is an important, productive part of the commercial timber harvesting land base (30.3% of the subzone[4]). The CWHxm is expected to experience concomitant pressure on its resources as pressure on the CDFmm land base intensifies.

Projected climate change presents an additional stress that may, on its own, or in combination with other pressures, cause ecological systems within the CDFmm land base to shift to other stable (or unstable) ecosystem states (Gunderson 2000; Scheffer et al. 2001). With general trends of increasing

4 The timber harvesting land base values were calculated using the 2014 B.C. Ministry of Forests, Lands and Natural Resource Operations consolidated timber harvesting land base layer.

5 The Madrone TEM project excludes CDFmm land area in the Fraser Valley and Gulf Islands National Park Reserve.

6 Elevation refinements are currently being evaluated based on additional field sampling for inclusion in future versions of provincial BEC linework.

temperatures and, potentially, greater moisture stress, species that are characteristic of the CDFmm (e.g., grand fir [*Abies grandis*], arbutus [*Arbutus menziesii*]) may establish farther northwards and up in elevation, and flourish in areas that are now within the CWHxm, while species that are characteristic of the CWHxm (e.g., western hemlock [*Tsuga heterophylla*]) may decline in vigour and relative abundance under the new climatic conditions. Community assemblages over time will depend on climatic trends and variability, effects of these conditions on other factors such as nutrient condition (e.g., through impacts on decomposer organisms), and other variables such as seed source and stochastic disturbance (e.g., MacDougall et al. 2008).

The CDFmm–CWHxm landscape provides an ideal opportunity to evaluate the effects of climate change and the potential to use concepts of ecological resilience as a framework for management in a highly human-modified landscape. Interactions among stressors may create positive feedback loops that further destabilize the ecological system across scales. For example, as the summer drought period increases, human settlement and recreation in the region may also increase. Water stress is expected to be compounded, and additional human presence is expected to exacerbate conditions of fragmentation, climatic stress (drought), and presence of highly adapted and competitive invasive species (plants, invertebrate pests).

1.1 Biogeoclimatic Ecosystem Classification Context for the Project

The BEC system is a hierarchical classification scheme that incorporates three classifications: climate, vegetation, and site. The subzone (e.g., CDFmm or CWHxm) is the basic unit of the climatic classification; it has a relatively homogeneous regional climate. Although subzones can be further divided into more refined climatic units, referred to as variants, the current coastal classification recognizes only one subzone of the CDF. Eastern and western variants of the CWHxm—CWHxm1 and 2, respectively—have been mapped, but the subzone level is currently used for management interpretations due to similarities in the properties of the variants (Green and Klinka 1994).

A BEC subzone is defined and recognized by the unique suite of plant species that occurs in characteristic relative abundance (i.e., the plant association) on mature zonal sites (i.e., sites that are intermediate in nutrients and moisture conditions and on which the plant community is primarily determined by climate rather than topoedaphic features within the subzone). For example, zonal sites in the CDFmm support the Douglas-fir – dull Oregon-grape plant community, whereas zonal sites in the CWHxm support the Western hemlock – Douglas-fir – Oregon beaked-moss plant community. Other, distinctive plant communities are described for sites that are relatively wetter (e.g., hygric) or drier (e.g., xeric) than the zonal moisture condition and are richer or poorer than zonal nutrient regime (MacKinnon et al. 1992).

The sites within a BEC subzone that support a specific plant association within that regional climate are called site series. These units represent areas of ecological space along gradients of relative soil moisture and nutrients within that subzone. Site series names include the subzone name followed by the plant association[7] name because the same plant association may occur

7 Technically, site series names incorporate the subzone and site association name. The site association is all sites across all regional climates that can support a specific plant association. The site association name draws on species from the mature plant association and, usually, is equivalent to the plant association name.

under different moisture conditions and nutrient regimes within other subzones.

In this report, regional climate refers to BEC subzones (greater study landscape); subregional climate refers to finer spatial and climatic units across a latitudinal gradient of a subzone (i.e., the transect). Site condition refers to moisture and nutrient regimes at the local (site) level. Site type or site unit (or, in this report, the term "ecosystem") also relates to the site series level of BEC and may reference a specific site series or a group of sites series determined by edaphic gradients (e.g., hygric, mesic, xeric); the site or plot is the location at which this level of edaphic (and climatic) influence on ecosystem structure, function, or composition is assessed.

The climate and site components at different levels of BEC are used as a framework for considering how the landscape and ecosystems of the dry south coast forests may shift with resource use and climate change. BEC provides a quantitative description of the best understanding of the relationships of plant communities to site conditions across different subregional climates of the province. The classification thus provides a rational basis for the development of hypotheses regarding new relationships between relative and actual moisture conditions, impacts on nutrient regime, and resultant community assemblages under climate change.

1.2 Project Objectives

The project was designed to identify:

1. the key ecological processes that structure the CDFmm and CWHxm landscape
2. the mechanisms by which shifts in ecosystem state could occur
3. the geographic subregions or site types (ecosystems) that are most vulnerable to state shifts within the study landscape
4. the variables that would be effective indicators of a likely state shift
5. the nature of changes to ecosystem attributes and processes associated with shifting states within this landscape.

It is anticipated that both ecosystem-level[8] (local site) and landscape-level[9] (regional study area) changes will occur with shifting bioclimate envelopes of species (e.g., Iverson et al. 2007; Evans and Cushman 2009) and communities (e.g., Wang et al. 2012a). Quantification of the current microclimate-vegetation-nutrient relationships (Figure 2) for CDFmm ecosystems described within the current BEC provides a basis for hypothesis development and subsequent testing of alternative projections at this scale. At the local site or ecosystem level, and at annual to (multi) decadal time scales, we hypothesize a shift in ecosystem structure, composition, and productivity along the characterized gradients of soil nutrient and moisture regime (i.e., edatopic grid) (Green and Klinka 1994) (Figure 3). For example, decreased summer moisture availability and lengthening of the summer drought season may cause a shift in the relationship between actual and relative moisture conditions (see left side of edatopes in Figure 3). Locations on the edatopic grid where soil moisture and nutrient conditions currently support site series 02

8 The plant community with associated microclimate and soil nutrient conditions; that is, BEC site series on a moisture-nutrient (edatopic) grid (Pojar et al. 1987). See Section 1.1; spatial scale of < 1 to approximately 10 ha.

9 Cluster of interacting ecosystems repeated in similar form throughout (Forman and Godron 1986); here, the study region (291 500 ha).

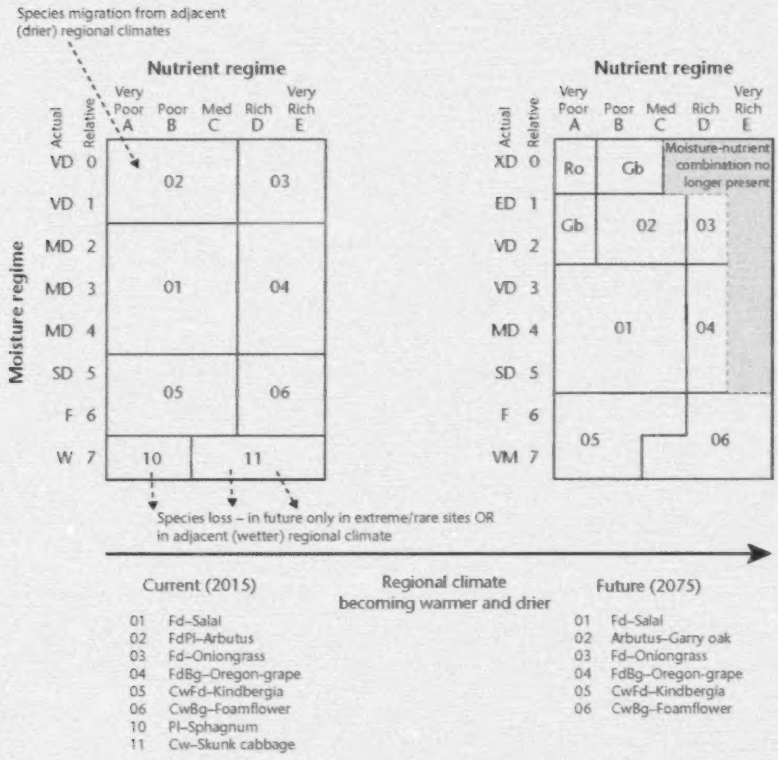

FIGURE 3 *Current edatopic grid (left) for the CDFmm subzone, and a hypothetical edatope (right) driven by modelled future (warmer, drier) regional climate (based on regional climate for the CDFmm land base projected using ClimateBC [http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna] using a HadGEM2-ES general circulation model and A2 emissions scenario). Moisture conditions are displayed as both actual (XD=extremely dry; ED=excessively dry; VD=very dry; MD=moderately dry; SD=slightly dry; F=fresh; VM=very moist; W=wet) and relative. Current and future site associations (and associated plant communities) are listed below for each time period. With the projected warmer climate and extended drought season, a realignment of the actual with relative moisture conditions is hypothesized. New plant communities will emerge because of changes in vigour of species under new combinations of climate and site, through re-assortment of species currently within the CDFmm landscape, and with migration of species from adjacent landscapes. Some moisture nutrient combinations will no longer support a forested community under the newer regional climate but may support Grassland (G) group communities (Gb=brushland class) or Rock outcrop (Ro) communities (MacKenzie 2012). Other moisture nutrient combinations may no longer be available due to, for example, moisture limitations on decomposition and nutrient turnover (and availability for plant uptake).*

and 03, both drier than zonal, may no longer support forested communities with the future combination of drier regional climate and relatively dry sites (e.g., hill crests or rapidly drained soils). Climate–site interactions may cause an increase in temperature or a decrease in moisture conditions such that decomposer activity is insufficient to maintain nutrient-rich plant communities. Novel biotic communities may also emerge at the extremes of nutrient and moisture availability. For example, those sites currently wetter than zonal (e.g., 05) may no longer be able to support western redcedar but may show increased vigour and growth of Douglas-fir within their plant communities.

At the regional spatial extent and at decadal or longer temporal scales, an entirely different edatopic grid may develop that reflects the interaction of a newly emerging, non-analogue regional climate (new zonal ecosystem) with shifting actual moisture and nutrient conditions at the site level. The distribution of communities at this scale will also be influenced by changes in disturbance regime. For example, reintroduction of a historic (pre-European settlement) surface fire regime (McDadi and Hebda 2008), either purposefully or as the result of increased intensity and temporal extent of seasonal droughty conditions, could cause Garry oak communities to expand within a complex of meadows and Douglas-fir stands.

Detection and description of climate-driven ecological change within the CDFmm–CWHxm landscape will draw on the comparison of quantitative relationships among microclimate, vegetation, and site condition. We expect that this research will identify ecological relationships and attributes that are resilient to climate stress relative to those that may respond quickly to climate change, and provide useful indicators of shifts in either geographic locale of current ecosystems or the emergence of new ecosystems. The initial field research focussed on understanding the interrelationships of ecosystem processes and the plant communities at the site level under current regional and microclimatic conditions. Subprojects were designed to refine and quantify the conceptual model of system dynamics in the CDFmm–CWHxm across levels of ecological organization. Microclimate, tree growth, decomposition rates of fine woody material, understorey (shrub) productivity, and ecosystem nutrient status were studied. Ongoing work will assess the utility of these features for detecting ecological shifts imposed by climatic change and for guiding sustainable resource stewardship within the CDFmm–CWHxm.

The project also incorporates objectives for extension of the data, scientific findings, and management implications of the research. We hope that extension of information on the research infrastructure, methodology, and outcomes will encourage additional work on these sites to advance resilience science and stewardship in the context of climate change.

As part of the project extension, this establishment report describes:

- the CDFmm–CWHxm study landscape
- the set of integrated research studies that examine climate–site–process relationships within the project
- the research infrastructure associated with the project
- the preliminary data and results for the research studies
- the next steps for the project.

1.3 Research Studies

Subprojects were developed to examine (hypothesized) critical drivers of current forest structure, composition, and dynamics within the study area. Within each subproject, focus was placed on selecting response variables and obtaining field measurements that are expected to provide effective indicators of ecosystem status and capture the complexity of processes that drive composition and structure in the dry south coast forests (Figure 2). However, the practicality of the variables as indicators of change across site types in the landscape was also considered. Factors such as ease, accessibility, and repeatability of measurement; time and expense to undertake fieldwork or lab analysis; and likelihood of response to disturbance or climate change in a time frame relevant to management were considered (Dale and Beyeler 2001). The initiation dates and timelines of the subprojects vary depending on the scale of the process examined and the resources available (Figure 4).

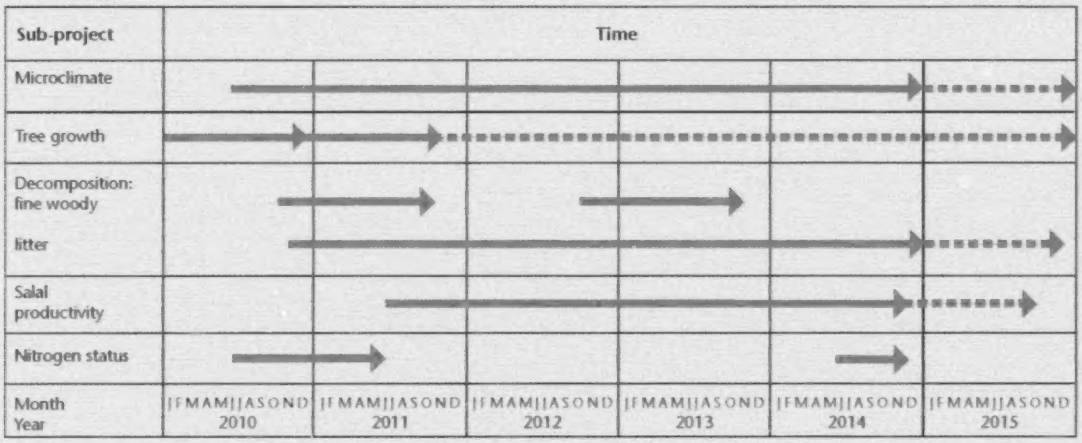

FIGURE 4 *Timeline of subprojects for the project. Solid lines indicate subprojects completed or currently under way; dashed lines indicate that the subproject is continuing through 2015 and potentially into future years.*

1.3.1 Microclimate Climate variability affects the distribution, composition, and productivity of forests (Notaro 2007). All atmospheric processes affect vegetation and soil processes, but microclimate influences these processes at relatively fine temporal scales (e.g., daily or seasonal versus multi-year) (Oke 1987). Microclimate is therefore one of the key drivers of the dynamics of ecological patterns and processes at the local scale (e.g., understorey vegetation composition, soil processes, and tree regeneration). Linking climate to soil and vegetation processes at the subregional scale requires an understanding of microclimate across the range of site conditions.

Soil moisture, in particular, is a strong determinant of the relative vigour, reproduction, and competitive abilities of plant species, and vegetation processes that produce the distinctive plant associations of BEC site series (Klinka et al. 1996). Soil moisture dynamics play a dominant role in vegetation stress and the suitability of vegetation to climate and soil conditions (Guswa 2002). Soil microclimate is also a strong determinant of local decay rates and extent, which influence nutrient availability and forest carbon pools

(Pastor and Post 1986; Trofymow et al. 2002). Soil moisture can function as a proxy variable for understanding the interaction between land surface and atmospheric conditions and evaluating patterns of climate change (Entin et al. 2000).

In this study, microclimate is measured on zonal sites that represent mesic, or average, soil moisture conditions and regional climate conditions in the CDFmm and CWHxm. Additionally, within the CDFmm, the microclimate of xeric (relatively drier than zonal) and hygric (relatively wetter than zonal) sites that are representative of sites where the ecosystem is influenced by regional climate in combination with edaphic (soil) and topographic (terrain) conditions are characterized. By quantifying microclimate parameters, the soil moisture balance can be calculated for each site type. Soil moisture balance is often the key functional expression of hydrological dynamics articulated in ecological patterns and processes (Rodriguez-Iturbe 2000). Therefore, projected shifts in climate inputs to the equations (e.g., precipitation) are being used to evaluate potential impacts to dry coastal ecosystems. Soil moisture is also being quantified to test whether this variable integrates climate and site conditions and links climate, soil, and vegetation interactions. If so, soil moisture may be an effective operational field indicator of climate change.

The objectives of the microclimate study are to:

1. determine the relationship between macroclimate and microclimate
    a. compare macroclimate, microclimate, and site relationships across a geographic distribution of the CDFmm and CWHxm study sites
2. characterize baseline microclimate conditions on all study sites
    a. compare daily, seasonal, and annual microclimate trends over the study period
    b. compare the means and variability in microclimate conditions
3. project future microclimate conditions in the CDFmm and CWHxm study area
4. identify microclimatic variables that are effective for monitoring and indicating impacts of climate change at multiple scales.

1.3.2 Tree growth Climate is the main driver of tree species distribution and forest productivity at regional scales (Woodward 1987; Boisvenue and Running 2006). Trees located near the edge of their distribution are potentially more susceptible to climate change impacts than those in the middle of a broad geographic species distribution (Spittlehouse 2003; Laroque and Smith 2005; Coops et al. 2007). Projections of climate change impacts on climate niche distributions of North American tree species generally predict expansion northward and upwards in elevation and contraction of southern and lower elevation distributions (Parmesan and Yohe 2003; Gray and Hamann 2013). Climate conditions may thus shift beyond the thresholds of species' current climate niches. Though rates of projected climate change vary, these changes will likely invoke maladaption symptoms (e.g., loss of productivity and vigour with increased environmental stress), particularly for species with slow rates of migration (e.g., trees) (Aitken et al. 2008; Fettig et al. 2013; Rehfeldt et al. 2014).

A dendrochronogical study is being conducted to evaluate the trends in growth patterns and the relationship between climate variability and growth

of coastal Douglas-fir (late successional, >80 years old) over the last two centuries. Long-term annual growth of trees was assessed on hygric, mesic, and xeric sites across the latitudinal distribution of the CDFmm and into the adjacent CWHxm. Xeric sites, which are subject to more intense droughty soil conditions, often give the strongest climate signal and understanding of long-term climate variability (e.g., Spittlehouse 2003). The sensitivity of tree growth and the nature of relationships of tree growth to climate on the xeric sites are being compared with the climate–growth associations on mesic and hygric sites, where soil moisture is less limiting. Effects of climate on tree growth can also vary temporally; for example, along the coast of British Columbia, these effects are influenced by the Pacific Decadal Oscillation (e.g., Chavardès et al. 2013). Thus, climate–growth relationships are being analyzed at broader temporal scales to assess interactions with inter-annual variation.

The objectives of the dendrochronology study are to:

1. determine the primary climate drivers of growth of Douglas-fir across spatial and temporal scales
    a. compare the climate drivers across spatial scales (regional, subregional, and site [local])
    b. compare the climate drivers across temporal scales (50 years, 30 years, annual)
2. project shifts in forest productivity and ecosystem structure with changes in climate
    a. identify geographic regions and site conditions where Douglas-fir may be most affected by projected changes in climate
3. evaluate the effectiveness of tree growth–climate relationships as indicators of climate change.

1.3.3 Decomposition rates The ecosystem processes of decomposition, and subsequent mineralization, of litter and downed woody material affect rates of nutrient cycling in forests, and thus nutrient availability for plants, and carbon and nutrient budgets of terrestrial landscapes (Waring and Schlesinger 1985). Rates and completeness of early stages of decomposition are affected primarily by climate, including moisture and temperature, and by litter quality through direct and indirect effects of these factors on the activity of microbes and soil organisms (Prescott 2005a). It is anticipated that changes in decay rates due to shifts in climate will affect nutrient availability for plant uptake and, potentially, reduce the resilience of ecosystems as they respond to shifts in these ecosystem functions.

The mechanism by which regional climate and macroclimate–microclimate interactions influence decomposition may vary across the latitudinal range of the study landscape and among the site types. At broad geographic and long time scales, mean annual temperature explains more of the variation in decay coefficients than mean annual precipitation (Zhang et al. 2008), though inclusion of summer precipitation can improve understanding of differential rates of decomposition across sites in Canada (Trofymow et al. 2002). Meentemeyer (1978) found that actual evapotranspiration (AET), which integrates temperature and precipitation, modelled decomposition well at regional scales. However, at local scales and where moisture may be limiting, mean annual precipitation may be the dominant factor influencing

decomposition rates (Aerts 2006; Zhang et al. 2008). In this study, standardized materials and protocols (EMAN 2004, 2006) are used to:

1. determine the relationship between environmental factors and decomposition rates of fine woody materials across the CDFmm–CWHxm landscape
    a. assess the feasibility of using decomposition rates as indicators of current ecosystem function across the geographic extent and gradient of sites in the study system
2. determine if decomposition rates can be used as an effective indicator of shifts in ecosystem function under climate change
    a. consider whether mechanistic relationships indicated by decomposition rates will drive predictable changes in above-ground plant communities.

1.3.4 Salal biomass and dynamics Salal (*Gaultheria shallon*) is a rhizomatous evergreen shrub that can form broad, clonal patches in the understorey of the CDFmm and CWHxm (e.g., Green and Klinka 1994; Huffman et al. 1994). The species provides browse for deer and elk, and forage for smaller mammals and birds, which consume berries (Haeussler et al. 1990). Salal also has ethnobotanical value as a food and medicine (Turner 1995), and is marketed as an ornamental (Cocksedge 2003). The shrub is ubiquitous in the study area: it forms a principal percentage of understorey shrub cover and biomass. However, salal is slightly less common in zonal sites of the CWHxm versus CDFmm and is less common in hygric-rich relative to zonal or xeric sites of the CDFmm (Green and Klinka 1994). Under some site conditions, salal can effectively maintain or expand its coverage, and thereby inhibit establishment of overstorey trees and growth of other shrubs, particularly after disturbance (Messier and Kimmins 1991; Tappeiner et al. 2001). The species competes aggressively for moisture on dry sites (Stanek et al. 1979) and may influence nutrient availability under a broader range of moisture conditions (Mallik and Prescott 2001).

Possible responses and adaptation of understorey species to climate shifts include changes in phenology (Wolkovich et al. 2012) and physiology (e.g., Aerts et al. 2009), and the interactions of these types of responses. Klassen's (2012) projections of bioclimate envelopes for salal suggest that the southern portions of the study landscape will remain suitable for this species in 2070–2099, whereas the central and northern portions will be unsuitable by that time. However, favouring of species adapted to warmer conditions, or physiologic change of existing species, can be attenuated by microclimate shifts at the site level (e.g., due to increased canopy cover [De Frenne et al. 2013]), which emphasizes the need to evaluate responses to climate shift subregionally. Further, the mechanism of these responses by salal, or other understorey species, may depend on the nature of the climate shift itself; for example, whether central tendencies or variability in climate variables are altered (Reyer et al. 2012). Shifts in reproductive success or vigour of salal could drastically change the community composition and vertical structural characteristics of dry south coast forest plant communities. Salal's recognizability in the field, well-known autecology, documented influence on dynamics of overstorey and other understorey species, and current differential cover by site and regional climate suggest that this species may be effective

for detecting and characterizing impacts of shifts in microclimate–macroclimate–site relationships in the study landscape.

The objectives of the salal study are to:

1. quantify biomass, regeneration, growth, and mortality of salal across
   a. the soil moisture gradient in the CDFmm
   b. the climatic gradient from the CDFmm to CWHxm
2. assess the utility of the following measures of salal for detecting climatic shifts and site-level responses of the vegetation community to climate change
   a. plant biomass or leaf size (area)
   b. nutrient content
   c. population dynamics (regeneration, mortality).

1.3.5 Ecosystem nutrient status Soil nitrogen (N) status has a strong influence on forest composition and productivity (Perakis and Sinkhorn 2011). Reconstruction of long-term records of soil nitrogen availability may be possible by analyzing tree-ring nitrogen isotope abundance (McLauchlan et al. 2007), which would provide insights about the stability of ecosystem structure over time and the resilience of forests to changing climatic conditions. The nitrogen status study examines the relationships among wood $\delta^{15}N$ of Douglas-fir, current soil nitrogen availability, and climatic conditions of the historical CDFmm landscape. Key results are provided in this report; additional details are presented in Kranabetter et al. (2013).

The objectives of the study are to:

1. calibrate nitrogen isotope abundance in wood currently produced by Douglas-fir to soil nitrogen availability across the contemporary CDFmm landscape
2. document ecosystem nitrogen status over the past century using $\delta^{15}N$ of increment cores, especially in relation to fluctuations in mean annual temperature, precipitation, and summer moisture deficits
3. assess the utility of these $\delta^{15}N$ relationships in detecting, predicting, and managing site- and landscape-level changes in ecosystem distribution and function with climate change.

2 STUDY DESIGN AND FIELD METHODOLOGY

2.1 Study Area

The study landscape includes the portion of Coastal Douglas-fir ecosystems (CDFmm subzone) that occurs on southeast Vancouver Island, and the adjacent transition to Coastal Western Hemlock temperate rainforests (CWHxm). The CDFmm is the smallest biogeoclimatic subzone on the coast of British Columbia: it covers approximately 252 000 ha (< 0.3% of the province). The subzone occurs on the southeast side of Vancouver Island and on the Gulf Islands, the southwest Lower Mainland, and part of the Sunshine Coast. The study sites within the CDFmm are located between Victoria, in the south, and Bowser, in the north, on Vancouver Island (Figure 5). The CDFmm has a Mediterranean-type climate characterized by warm, dry summers and mild, wet winters (Green and Klinka 1994). The mean annual

temperature is 9.6°C, and the mean warmest month temperature is 16.9°C; the mean annual precipitation is 1065 mm, and the mean summer precipitation is 196 mm (Table 2).

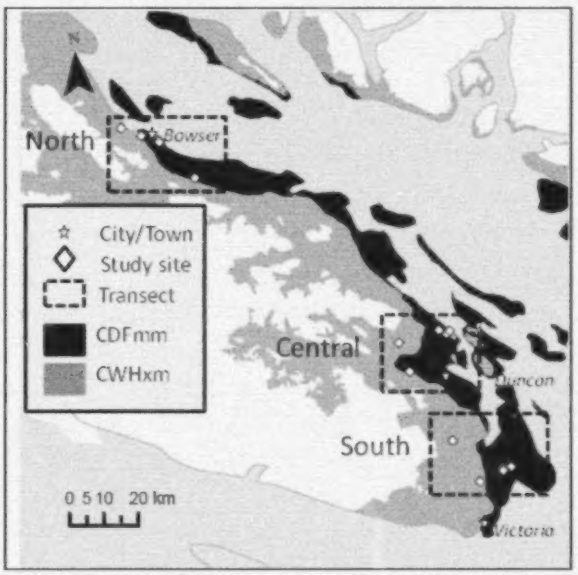

FIGURE 5 *Location of the 15 field sites grouped by the north, central, and south transect in the CDFmm and CWHxm biogeoclimatic subzones on southeastern Vancouver Island. There are five field sites per transect, though some CDFmm points overlap due to close proximity.*

TABLE 2 *Climate normals (1961–1990) for CDFmm and CWHxm biogeoclimatic subzones in British Columbia. The mean and standard deviation were calculated from values of climate variables (Climate WNA; Wang et al. 2010) for all points where a 1 km resolution grid intersected each biogeoclimatic subzone (BC MOFR 2011).*

	CDFmm		CWHxm	
Climate variable	**Mean (N = 3597)**	**Standard deviation**	**Mean (N = 10515)**	**Standard deviation**
Mean annual temperature (°C)	9.6	0.3	8.7	0.8
Mean warmest month temperature (MWMT; °C)	16.9	0.4	16.5	0.7
Mean coldest month temperature (MCMT; °C)	3.2	0.5	1.8	0.9
Temperature difference between MWMT and MCMT (°C)	13.7	0.7	14.7	0.8
Mean annual precipitation (mm)	1065	169	1901	647
Mean summer precipitation (mm)	196	45	335	104
Annual frost-free period (days)	218	19	191	23
Annual precipitation as snow (mm)	43	14	143	98

The CWHxm covers approximately 958 300 ha (1.0% of the province). This subzone occurs adjacent to the CDFmm, both westward (typically at higher elevations) and northward (Figure 1). The CWHxm study sites are located west of the CDFmm sites between Victoria and Bowser on Vancouver Island (Figure 5). Annual and seasonal trends in regional climate for these subzones are similar, though overall, the CWHxm is slightly cooler and wetter than the CDFmm. In the CWHxm, the mean annual temperature is 8.7°C, and the mean warmest month temperature is 16.5°C; the mean annual precipitation is 1 901 mm, and the mean summer precipitation is 335 mm (Table 2). These climatic differences result in a shorter growing season in the CWHxm and a summer soil moisture deficit in the CDFmm. Differences in air temperature and moisture regime are sufficiently distinct to differentiate dominant tree species composition on zonal (or mesic) sites[10]: the CDFmm is dominated by coastal Douglas-fir; the CWHxm is dominated by Douglas-fir and coastal western hemlock (*Tsuga heterophylla*) (Green and Klinka 1994).

2.2 Site Selection and Characterization

Three transects were established to evaluate changes in climate–vegetation–site relationships subregionally across the latitudinal range of the CDFmm on Vancouver Island: the southern transect is in the Victoria area, the central transect is in the Duncan area, and the northern transect is in the Bowser area (Figure 5). The transects are located in areas that are projected to have increased summer moisture deficit by mid-century (2041–2070) (Wang et al. 2010).

Five plots were established on each of the three transects to sample a range of soil moisture conditions: (1) CDFmm xeric, (2) CDFmm mesic, (3) CDFmm hygric, (4) CDFmm–CWHxm transition (TRN) mesic, and (5) CWHxm mesic (Figure 6). The CDFmm, CDFmm–CWHxm transition, and CWHxm mesic sites were established to detect and evaluate changes in ecosystem attributes that may signal a geographic shift in regional climatic conditions across the transition from the (currently) relatively warmer and drier CDFmm to the cooler and wetter CWHxm. The CDFmm edaphic sites (xeric and hygric) were established to improve understanding of the interactive influence of site and climate on ecological variables and to monitor and compare any shifts in ecosystem attributes among site types within the CDFmm.

Site candidates were evaluated based on current ecosystem mapping (BEC [BC MOFR 2011], TEM [Madrone 2008]), forest age, topography (elevation, aspect, proximity to water bodies [Terrain Resource Information Management][11]), and access from roads and railways. Land ownership and site security were considered when establishing field sites in an attempt to minimize visibility from public corridors. Preference was given to study sites with mature to late seral forests (>80 years old) that were larger than 1 ha, and which met logistical criteria, including truck accessibility and proximity to roads, in order to reduce travel time.

Ecological descriptions of site, soil, forest structure, and vegetation composition were completed for each study site according to provincial methodologies and standards (BC MOELP and BC MOF 1998). Physical site data

10 Mesic sites are intermediate in soil moisture and nutrient regime in a given area. Zonal sites best integrate the effects of climate on vegetation growth rather than the effects of topography or edaphic condition, and thus, are typically mesic sites.

11 Available at www.geobc.gov.bc.ca/base-mapping/atlas/trim/index.html.

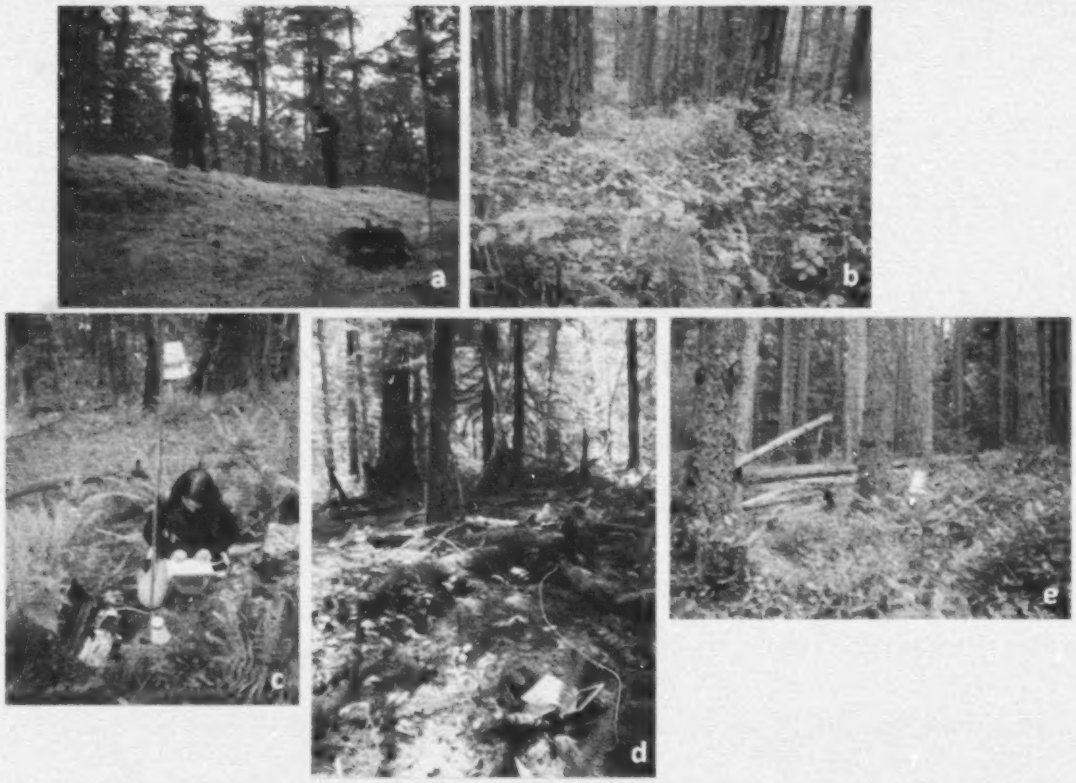

FIGURE 6 *The five site types from the south transect: (a) the CDFmm xeric, (b) mesic, and (c) hygric sites, (d) the CDFmm–CWHxm transition mesic site, and (e) the CWHxm mesic site.*

collected included geo-referenced location, aspect, slope, elevation, meso-slope position, and surface topography. The successional status and structural stage of the forest stand were also recorded. The soil moisture and soil nutrient regimes of each plot were determined based on the site and soil features described.

One soil pit was dug to describe the soil profile of each site outside the instrumented sampling area. Soil depth, structure, and biological activity were documented for all organic layers; soil depth, colour, texture, structure, and percent coarse fragments were recorded for mineral horizons. Humus form, rooting depth, rooting zone particle size, and root restricting layer were also noted. The primary water source and drainage class for the rooting zone were recorded.

Forest structural data were collected on each site. Species, diameter, length, and decay class of each of piece of CWD along two 24-m transects from plot centre were recorded. Live and standing dead trees were sampled within one variable-radius mensuration plot at each study site, and species, dbh, height, crown class, tree class, pathological indicators, and damage type and severity were recorded. Mensuration plots were established using a Basal Area Factor that incorporated 7–11 trees (>7.5cm dbh) in the sample.

Percent cover of all species of vegetation in a 20 x 20 m (400 m²) plot was recorded by vertical stratum: A: tree; B: shrub; C: herb; D: moss/lichen/seedling. A hemispherical photo was taken above each of the three soil microclimate subplots (Section 2.3.1) at each study site to describe the canopy cover and light environment directly above the soil moisture sensors. Two series of photos were taken using a tripod-mounted Canon digital SLR camera with a Sigma 8-mm fish-eye lens levelled (1) at the ground surface, and (2) at 1.5 m above the ground surface (above the shrub layer).

2.3 Research Studies

2.3.1 Microclimate In June 2010, each study site was established, and included three soil microclimate subplots and one air temperature station around the plot centre (centre of each study site) (Figure 7). The subplots were located at the points of an equilateral triangle to characterize the within-plot soil variability and minimize autocorrelation among the soil microclimate samples. Microclimate stations were installed on the CDFmm and CWHxm mesic sites (2010) and on the three CDFmm–CWHxm transitional sites (2013). Site layout was modified as necessary due to soil coarse fragment content, tree locations, or insufficient soil depth.

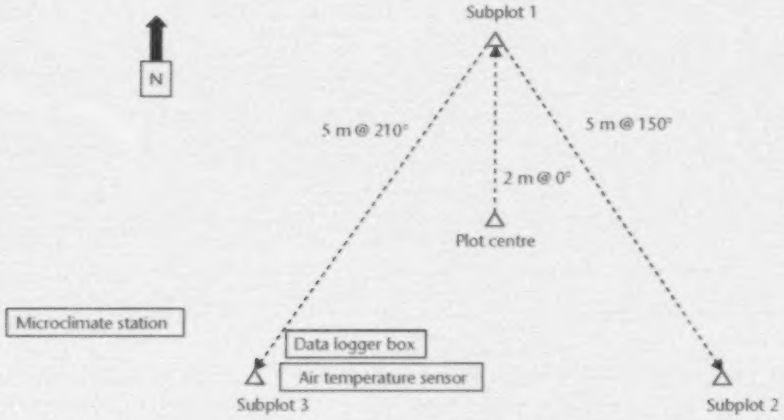

FIGURE 7 *Site layout with the three soil microclimate subplots, the data logger box, and air temperature sensors positioned around the plot centre. The CDFmm and CWHxm mesic sites also include an additional microclimate station located adjacent to soil microclimate subplot 3. The CDFmm–CWHxm transitional site microclimate stations were installed in 2013.*

Soil moisture, soil temperature, and air temperature

Each study site ($N = 15$) was equipped with soil moisture, soil temperature, and air temperature sensors. The soil moisture and soil temperature sensors were installed 25 – 30 cm below the ground surface at the three subplots (Figure 8).

Decagon EC-5 soil moisture sensors (Appendix 1) were buried at 25 – 30 cm depth in each of the three subplots at each study site. The sensors were inserted downward at an angle into the soil profile on the upslope side of the soil pit (Figures 8b, c). If a sensor hit rock or roots, it was re-inserted into undisturbed soil. In rocky soils, a soil knife was used to create a channel so the

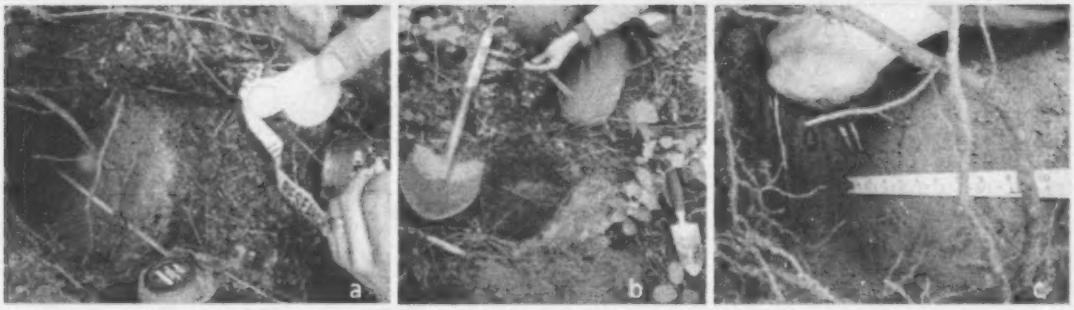

FIGURE 8 *(a) Thermochron iButton® sensor (small metal disc) being inserted into the rooting zone soil horizon (ca. 27.5 cm depth) to measure soil temperature adjacent to the Decagon EC-5 soil moisture sensor, (b) soil pit dug to insert the Decagon EC-5 soil moisture sensor, and (c) the soil moisture sensor installed into the rooting zone soil profile (25–30 cm depth).*

sensor could be inserted without damage but so it still maintained contact with the soil (i.e., there were no air pockets to capture water). The sampling depth (25–30 cm depth) targeted the rooting zone for vegetation growing on the forested sites. The soil moisture sensors record volumetric water content (%), the ratio of the volume of water within a 0.2 L measurement volume (including soil particles, air spaces, and water volume).

The soil temperature sensors were inserted into the side of the soil pit at the mid-point of the soil moisture sensor sampling range (i.e., 27.5 cm). Copper-constantan thermocouples and Thermochron iButtons® were used to sample air and soil temperatures (Appendix 1).

Two air temperature thermocouple sensors were mounted on aluminum stakes (0.3 and 1.5 m above the ground surface). The air temperature sensors were housed in radiation shields so ambient air temperature was measured rather than the effects of radiative heating associated with direct-beam solar radiation. Radiation shields were camouflaged with sword fern fronds to reduce visibility and the risk of human and animal interaction with the equipment (Figure 9a).

Additional microclimate measures on CDFmm and CWHxm mesic sites

Five additional microclimate measurements were recorded on the mesic study sites using Onset HOBO® data loggers and sensors to evaluate microclimate more intensively, and over time, to calculate soil water balances (Figure 9d). Relative humidity, air temperature, precipitation, solar radiation, and wind sensor specifications are detailed in Appendix 1. The microclimate station tripod was located as close as possible to subplot 3 but outside the subplot layout (Figure 7).

Relative humidity and air temperature measurements were recorded jointly by one sensor mounted in a radiation shield 1.5 m above the ground on the north side of the microclimate station tripod at each site. Precipitation was measured with Onset HOBO® rain sensors, which consisted of tipping bucket rain gauges mounted on the tripod 3 m above the soil surface on the north side of the tripod. Subcanopy solar radiation was measured with a HOBO® silicon pyranometer sensor mounted 1.0 m above the soil surface on the south side of the tripod in order to monitor light availability to the under-

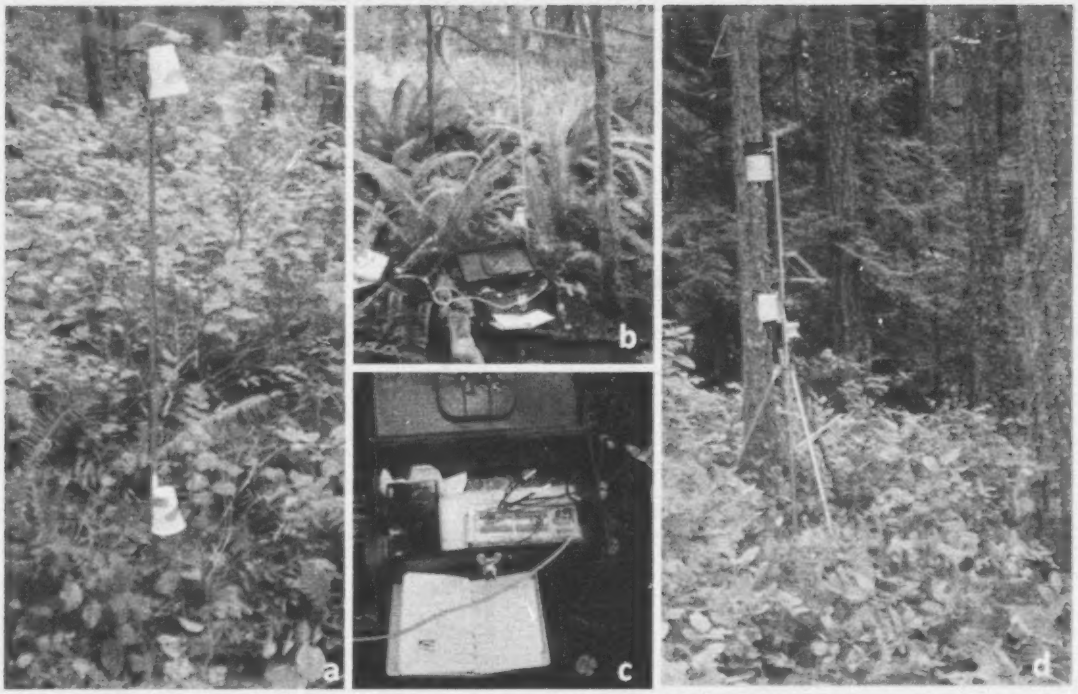

FIGURE 9 *(a) Thermocouple air temperature sensors with radiation shields placed 0.3 m and 1.5 m above the ground surface, mounted on a metal stake adjacent to subplot 3, (b) data logger box and air temperature sensors adjacent to subplot 3, (c) the Campbell Scientific CR10 data logger and Panasonic 12 V battery in the data logger box, and (d) HOBO® microclimate station showing the tripod and mast structure that house the wind speed, precipitation, air temperature and relative humidity, and solar radiation sensors, and with a HOBO® U30 data logger powered by a solar panel.*

storey vegetation. Wind speed was measured at 3.3 m above the soil surface on the south side of the tripod at each site.

Data loggers

Campbell Scientific CR10 data loggers and HOBO U30 data loggers recorded microclimate data at the study sites (Appendix 1). All data loggers were programmed to record data at 1-hour logging intervals, with sampling ranging from 15-second to 4-minute intervals; mean values were saved on the hour. The data loggers were housed in a water-resistant plastic box that was placed on the ground surface next to subplot 3 or was mounted on the climate station tripod (Figures 9b, c, d).

2.3.2 Tree growth Douglas-fir trees were sampled at each of the 15 sites, at the end of two field seasons (south transect in October 2010, central and north transect in October 2011). Tree cores were taken at approximately breast height (130 cm above ground) from 10–20 healthy, dominant, and co-dominant trees per site. Trees were drilled to pith or as close as possible. For older, larger-diameter trees, core lengths were limited by the length of the corer or if the centre of the tree was rotten. The sample trees were

tagged and photographed. Field notes, including tree height, dbh, and any signs of disease, pathogens, and physical irregularities, were recorded. Cores were inserted into plastic straws and stored in the freezer until they were processed.

2.3.3 Decomposition rates The study on the relationship of decomposition rate to climate, soil depth, and soil horizon was initiated in October 2010. For the first trial, decomposition sticks were placed in the field between October 12 and 21, 2010 and were retrieved between November 22 and 29, 2011. The second trial was initiated between September 27 and October 4, 2012, and the decomposition sticks were retrieved from the field between October 17 and 28, 2013. Methodologies were based on protocols developed by the Ecological Monitoring and Assessment Network (EMAN 2004, 2006).

The decomposition sticks were white birch (*Betula papyrifera*) tongue depressors, which were used as a standardized decomposition substrate that was representative of fine woody material (EMAN 2006). A 2-mm hole was drilled in the end of each stick so zap straps with labels could be attached and the sticks could be tied to markers in the field. Sticks were dried at 70°C overnight (8 hr), then cooled for 10 minutes and weighed to the nearest 0.0001 g.

Three decomposition sticks were prepared for each of the three subplots at a site, one each for insertion into the L, F, and B horizons of a subplot (i.e., $N = 135$ total across the three transects and five sites). A tag with a unique label that identified the transect, site, subplot, and soil horizon in which the stick would be deployed was attached to each stick. The sticks were stored in Ziploc® bags with desiccant until they were placed in the field (within 3 days of initial processing).

In the field, the decomposition sticks were placed in their groups of three at a 1-m offset from the microclimate subplots (Section 2.3.1, Figure 10a). Sticks were inserted into the soil profile with their vertical axis parallel to ground surface at the following depths from the soil surface: L: litter horizon, 0–2 cm; F: friable organic horizon, 3–5 cm; and B: mineral horizon, 19–27 cm.[12] Decomposition sample subplots were marked with pigtail markers to which the decomposition sticks were attached using monofilament fishing line (Figure 10b). When the sticks were removed from the field, they were placed in labelled envelopes in the freezer until they were processed in the lab.

2.3.4 Salal biomass and dynamics During spring 2011, three quadrats were established in each of the 15 study sites to measure total salal biomass, current year's growth, and foliar attributes (Figure 11). Quadrats in study sites on the south and central transect were marked for ongoing evaluation of salal dynamics (regeneration, growth, and mortality). Quadrats were 1 × 1 m and were located systematically to ensure site type was consistent. Plots were required to have ≥25% salal cover to ensure that there was an adequate number of stems to develop height–biomass relationships.

The percent cover of salal, other shrubs, herbaceous species, and bryophytes in all quadrats on each study site was visually estimated. Four

12 The second field trial followed similar protocols to the first, except that the decomposition sticks were placed in mesh (onion sack) bags, rather than directly into the soil, to reduce the potential loss of samples when extracting the sticks from the field.

FIGURE 10 *(a) Fine woody material samples (decomposition sticks) were inserted into each of three soil horizons (L, F, and B) to measure the decomposition rate at each subplot (N = 3) of a site (N = 15 sticks per site); (b) decomposition sample sites were marked with a pigtail marker, and individual decomposition sticks were tied to the marker using monofilament fishing line.*

FIGURE 11 *Establishing salal quadrats in the 2011 growing season.*

densiometer readings, one in each cardinal direction, were taken at 1.4 m height in the centre of each quadrat and were averaged to provide a single percent overstorey cover value for the plot. All salal stems originating within a quadrat were flagged at the base, and the initiation point of the current year's new growth was marked with nail polish. It was necessary to identify the current year's growth in early summer because by fall, the colour of the new stem and leaves is indistinguishable from that of the older stems.

At the end of growing season (September 23–26, 2011), all salal that had been flagged in the quadrats was clipped to within 2 cm of the ground surface. All stems were bagged and taken to the lab for processing. Fifteen salal leaves from the current year's growth were randomly selected and removed for additional measurement of leaf attributes, including biomass and nutrient concentrations.

Between October 2 and 9, 2012, new stems (dead and alive) on all salal quadrats on the central and north transects were tallied. The stems were marked at the base with blue wool. Regeneration (dead and alive) from the 2013 growing season, and 2012 stems that had died over the previous year were tallied between November 5, 2013 and January 14, 2014. All regeneration was marked with pink wool.[13]

2.3.5 Ecosystem nutrient status The study on ecosystem nitrogen status involved 15 sites, and provided three replicates of each of five site series of the CDFmm (Green and Klinka 1994): (02) xeric and very poor; (03) submesic and poor; (01) mesic and medium; (04) moist and rich; and (06) subhygric and very rich. Three of these study sites—one (02), one (01), and one (06)—corresponded to the CDFmm plots on the south transect used in the other subprojects; that is, CDFmm xeric, mesic, and hygric sites. The additional 12 study sites were located within the south transect subregion, within 20 km of Victoria, but were unique to the nitrogen status subproject.

In spring 2010, at the onset of the active growing season, soils were incubated in situ at 0–15 and 15–30 cm depths at five random locations within each plot. Soil cores were extracted with a soil auger, poured gently into polyethylene bags, and placed back into the hole. Forest floors were not sampled separately because most microsites had mineral soil directly beneath the litter.

Increment cores were taken from three co-dominant Douglas-fir trees on each plot in February 2010. In October 2010, the current-year tree ring deposited over the growing season was sampled from nine co-dominant Douglas-fir trees using an increment corer, and the samples were bulked into three subsamples.

3 DATA DEVELOPMENT AND ANALYSIS

3.1 Site Attributes

The ecological plot data were entered to the provincial BEC database, where they were summarized to complete the ecological descriptions, including site, vegetation, and soil characteristics, for each plot. Summary tables were produced in Excel using built-in macros within the provincial relational database program VPro.[14] Tabular summaries that integrate constancy and percent cover data for vegetation were generated to compare the sites. For CWD, the number of pieces and the mean length and diameter of pieces at each site were examined. The total number of pieces by species across decay classes was determined for each site type. For live trees, mean dbh and mean tree height at each site, and the mean number of trees by species across height classes by site type were calculated. The total number of trees by species across height classes was determined for each site type.

13 A final assessment of regeneration and mortality was conducted at the end of the 2014 growing season. The plots were re-clipped to assess the biomass of the 2014 year and the cumulative (all 3 years) growth since the initial clip was done; these samples will be processed and weighed as per the initial clipped salal. The first 2 years' count data are presented here pending processing of second set of clipped salal samples.

14 Available at www.for.gov.bc.ca/hre/becweb/resources/software/vpro/index.html.

The hemispherical photos were analyzed using WinSCANOPY® software (Regent Instruments Inc. 2006), which calculated the photosynthetic photon flux density (PPFD). PPFD over the canopy average for the growing season was a measure of the photosynthetically active radiation for the site. Mean and standard error were calculated for the CDFmm xeric, mesic, and hygric sites ($N = 3$ plots per site type), the south, central, and north transects ($N = 5$ plots per transect), and the CDFmm, CDFmm–CWHxm transition, and CWHxm mesic sites ($N = 3$ plots per subzone and the transition). A one-way ANOVA was used to test for differences in mean PPFD among the CDFmm sites, the transects, and the subzones. Where significant differences were found, ANOVAs were followed by Tukey post-hoc tests using the multcomp package in R to test for differences in means between each pair of sites, transects, and subzones (Hothorn et al. 2008; R Core Development team 2010).

3.2 Research Studies

3.2.1 Microclimate Daily air temperature and precipitation data from the Victoria Airport climate station were downloaded from the Government of Canada historical climate data website (Government of Canada 2014). The south transect CDFmm mesic site data were compared to data gathered at the Victoria Airport climate station (48°38'50"N, 123°25'33"W, 19.5 m elevation), and were used to investigate the difference between microclimate (forest site) and macroclimate (open site). Mean annual air temperature and mean total precipitation for the June 1, 2010–May 31, 2013 period were compared. A more detailed macroclimate–microclimate analysis will be completed when additional macroclimate and microclimate data are collected and are available over a longer period.

The digital microclimate data were compiled and standardized to an hourly data format. Daily summaries for each study site for the initial 3 years of data sampling (June 1, 2010–May 31, 2013) were created using the plotrix package and the stats package in R statistical software (Lemon 2006; R Core Development Team 2010). Mean daily values were used for subregional and site comparisons.

The daily soil moisture and temperature values for the CDFmm xeric and hygric sites and the daily precipitation from the CDFmm zonal site on the south transect were plotted over time (precipitation was not sampled on the edaphic sites). The time series showed the length of the data series and the temperature and moisture cycles and patterns within the initial 3 years of data collection (June 1, 2010–May 31, 2013). These series also illustrated the data gaps that were common in the initial 4 months of data collection, and the winter precipitation data gaps due to wind storms and sub-zero conditions, which impeded the proper functioning of the tipping bucket mechanism used to sample precipitation.

Mean annual temperature, moisture, precipitation, relative humidity, wind speed, and solar radiation variables were summarized (mean and standard deviation) using the mean daily values for each study site during the June 1, 2010–May 31, 2013 time period ($N = 1095$). Precipitation was calculated as the sum of the mean daily amounts, and then was averaged over the 3 years. The precipitation, relative humidity, wind speed, and solar radiation data for the CDFmm–CWHxm transition sites were not included in the summary because these stations were installed in spring 2013; therefore, <1 year of sampling data was available.

Walter and Lieth climatic diagrams were created with the climatol package in R statistical software (Guijarro 2011) for the CDFmm and CWHxm zonal sites using three-site (i.e., one site from each of three transects) averages[15] for monthly total precipitation and mean, minimum, and maximum air temperature values for each subzone. These figures provided a visualization of the dry and moist seasons and potential frost period during the first 3 years of sampling, and the minimum and maximum monthly temperatures.

3.2.2 Tree growth The tree core samples were processed at the University of Northern British Columbia's Tree Ring Laboratory over a 3-year period (south transect 2010–2011, north transect 2011–2012, central transect 2012–2013). Tree cores were sanded to enhance the contrast in the annual growth rings.

After being visually cross-dated at the local level, growth rings were measured to the nearest 0.001 mm using the Velmex ring-measurement system (Velmex Inc. 1992) interfaced with Measure J2X (VoorTech Consulting 2004), and a growth chronology was developed by averaging annual ring widths for all cross-dated cores at each site using the dplR package for R software (R Development Core Team 2008). Prior to averaging, long-term trends, presumably related to age and stand dynamics, were removed from each tree's growth series using a negative exponential curve (Cook 1985). A site-specific autoregressive model was then applied to each tree series, and residuals for each tree were averaged to form a pre-whitened growth index with zero serial autocorrelation. The initial chronology results from the south transect are presented in this report. The percent growth decline for each site on the south transect was calculated for the 1981–2009 period (growth decline = 1-[2009 growth/1981 growth]). The complete dendrochronological analysis on all 15 sites will be presented in future reports.

Average annual tree growth on the south transect in the CDFmm xeric site was plotted against annual climate variables that influenced growth at each site. Climate data were obtained for the Victoria Airport climate station (Government of Canada 2014). Simple linear regression was used to test the relationship between average annual growth and summer precipitation.

3.2.3 Decomposition rates In the lab, the decomposition sticks were removed from the freezer, scraped with a dissection needle to remove fungal hyphae and debris, and rinsed. The sticks were dried at 70°C for 8 hours, cooled for 10 minutes, and reweighed. The surface area of each stick was measured with ImageJ v.1.46 (Rasband 2012). ImageJ was also used to measure the surface area of 10 pre-deployment decomposition sticks in order to calculate the average area of a "standard" pre-deployment stick.

For each decomposition stick, a standardized mass loss (g/mm^2 surface area) over the 1-year deployment trial was calculated. For the three subplots at each site, mean mass loss was determined for the L, F, and B horizons, and for all three horizons combined.

Trends in mass loss across site types within the CDFmm (hygric, zonal, and xeric sites), across climatic conditions (mesic sites of the CDFmm, CWHxm, and transition), and across latitude (south, central, and north transects) were examined. The relationships between mass loss and soil moisture

15 Calculated using daily means for the 3 years of sampling.

and temperature were studied using scatterplots, correlation, and simple linear regression. Climatic variables were averaged annually and seasonally (summer and fall). Summer was defined as May 1 to September 1, inclusive; fall was defined as October 1 to November 1, inclusive.

Only the results for mass loss in the B horizon are presented in this report because they were most easily interpreted across soil moisture gradients within the CDFmm and among the three sets of zonal sites. Furthermore, the soil temperature and moisture data that were correlated with mass loss were collected at approximately the same depth as the B horizon across subplots. The depths of L and F horizons related less consistently to microclimate measurements in the field.

3.2.4 Salal biomass and dynamics For each quadrat, the total number of salal stems, the length of each stem (both total and current growth), and the total stem age (based on terminal bud scars) (Huffman et al. 1994) were recorded. Stems were separated into components (total and current stems, leaves, and flowers/berries) for drying (70°C for 24 hours), and dry weights were measured for each component.

The 15 salal leaves that were processed separately were freeze-dried (3 days at 50 bars), and these dry weights were added to the current year's leaf biomass. These leaves were scanned and the leaf area was determined using ImageJ v.1.46 (Rasband 2012). The leaves were subsequently frozen until analysis of nutrient and tannin concentrations could be conducted. Tannins were analyzed by a colorimetric assay of proanthocyanidins after treatment with ferric ammonium sulphate using a UV spectrophotometer (FAO 2000). A laboratory control was developed with condensed tannins supplied by the Canadian Forest Service. Nitrogen, carbon, and sulphur content were determined for each leaf by dry combustion with a Fisons/Carlo-Erba NA 1500 NCS analyzer (Kalra and Maynard 1991).

Site effects on foliar attributes and salal growth were examined across the xeric, zonal, and hygric sites of the CDFmm (all three transect combined) using one-way ANOVA. Graphical analysis and simple linear regression were used to assess the influence of climate (mean annual precipitation, mean annual temperature, and annual heat:moisture index) on leaf nutrient content and mass of the stem components (mesic sites in the CWHxm, CDFmm–CWHxm TRN, and CDFmm across all three transects). The climate data were extracted using ClimateWNA (1961–1990 reference period) (Wang et al. 2012b).

Numbers of regenerating and dying stems were tabulated for comparison across site types, zonal climates, and transects (subregions) for the 2012 and 2013 growing seasons.

3.2.5 Ecosystem nutrient status After an 8-week incubation period, the soil samples were retrieved and immediately sieved and analyzed for amino acids, ammonia, and nitrate concentrations.

Tree cores were oven dried and lightly sanded where necessary to differentiate tree rings under magnification. Samples from 3-year tree ring increments were separated with a chisel, going from 2009 back to 1900 (36 samples per core), and were combined by sample period among the three trees. Trends in wood $\delta^{15}N$ over time were fitted to regressions for each plot and then were de-trended to accommodate potential differences in stand condi-

tions and site history. Residual $\delta^{15}N$ was determined for each 3-year sample period by subtracting the data point from the fitted regression. De-trended residuals in climatic variables were also calculated for the corresponding 3-year period of tree ring sampling by fitting regressions to the climatic data recorded for Victoria.

4 PRELIMINARY RESULTS

4.1 Site Attributes

Site and soil characteristics for the 15 study sites are presented in Table 3. The sites varied in slope (0–55%) and aspect (but no south- or north-facing slopes). All sites were at elevations ≤ 250 m, and the CWHxm sites were at the highest elevations. Successional status ranged from young climax to mature climax, and structural stage ranged from young to old forest at edaphic (xeric and hygric) sites and climatic (mesic) sites. Stand age ranged from 60 years in the second-growth stands to more than 186 years[16] in the unlogged stands. The zonal plots were located in the mid slope position, the hygric sites on lower slopes, and the xeric sites on crests or level slope positions. Soil drainage classes ranged across sites (very rapid and rapid on xeric and mesic sites, well and moderately well on mesic and hygric sites), and there was a broad range of rooting zone particle sizes across all sites. Rooting depths ranged from 18 to 72 cm. Xeric sites were shallower due to lithic contact; hygric sites had greater soil depths. Soils were Podzols and Brunisols, with the exception of a Gleysol on the central transect at the CDFmm hygric site. Humus forms included a variety of Mors, Moders, and Mulls, with thicknesses ranging from 1 to 25 cm. The combination of unique features of each site results in the soil moisture conditions targeted for the study design (e.g., level slope position with high coarse fragment content results in rapid drainage on a xeric site). Sites were classified as having relative soil moisture regimes of 1 (very dry; CDFmm xeric), 5–6 (slightly dry to fresh; CDFmm hygric), and 3–4 (moderately dry to fresh; CDFmm, CDFmm–CWHxm transition, and CWHxm mesic) based on the integration of site and soil features.

In total, 135 pieces of CWD were sampled on the 15 study sites (Table 4). The mesic sites had the most Douglas-fir CWD. The CDFmm hygric sites had the highest diversity of species (three to five per site), while the CDFmm xeric sites had the fewest pieces (one to four per site) and the lowest diversity of species (one to two per site).

The mean diameters of CWD per site ranged from 8.0 cm (CDFmm hygric site on the south transect) to 36.0 cm (CDFmm hygric on the north transect). The mean lengths of CWD per site ranged from 1.0 m (CDFmm xeric site on the south transect) to 22.7 m (CDFmm hygric site on the central transect and CWHxm mesic site on the south transect).

The mesic sites had up to 24 pieces of CWD ($\bar{x} = 12$ [± 6.1 SD] per site). The TRN and CWHxm mesic sites included pieces in all five decay classes (Figure 12). Decay class were defined primarily by wood texture (1: hard, 2: sapwood rot, 3: advanced decay, 4: extensive decay, and 5: small pieces, soft portions).

16 Veteran trees were found in some plots, but the diameters were too large (> 100 cm dbh) to core to the centre of the stem to obtain an accurate tree age.

TABLE 3 *Site and soil descriptions for the 15 study sites—CDFmm xeric, mesic, and hygric, the CDFmm–CWHxm transitional (TRN) mesic, and CWHxm mesic sites—presented for each of the south (S), central (C), and north (N) transect sites*

	CDFmm xeric			CDFmm hygric			CDFmm mesic			CDFmm–CWHxm TRN mesic			CWHxm mesic		
Transect	**S**	**C**	**N**	**S**	**C**	**N**	**S**	**C**	**N**	**S**	**C**	**N**	**S**	**C**	**N**
Location	Thetis Lake Park, Victoria	Maple Mountain, North Cowichan Regional District	Melrose Road, Whiskey Creek	Francis King Park, Victoria	North Cowichan Regional District Community Watershed	Lighthouse Community Trails, Bowser	Thetis Lake Park, Victoria	Maple Mountain, North Cowichan Regional District	McColl Road, Bowser	Waugh Creek on Kapoor Main, Victoria Watershed	Holt Creek, Cowichan River Provincial Park	Bowser Ecological Reserve; Plantation FSR	CRD Watershed, Sooke Lake entrance, Victoria	Chemainus River Provincial Park	Rosewall Creek Forest Service Road; west of Fanny Bay
Longitude	123°28'50"	123°37'60"	1243°32'30"	123°27'0"	123°39'38"	123°40'11"	123°28'59"	123°37'13"	124°40'0"	123°34'46"	123°47'43"	124°44'6"	123°39'5"	123°49'23"	124°48'39"
Latitude	48°28'49"	48°50'38"	49°19'25"	48°28'56"	48°51'22"	49°25'49"	48°28'3"	48°51'3"	49°25'31"	48°27'19"	48°45'32"	49°26'56"	48°34'11"	48°50'17"	49°28'22"
Elevation (m)	95	233	150	53	145	42	75	130	42	200	105	95	250	238	40
Relative soil moisture regime[a]	1	1	1	6	5	6	3	3	3	4	3	3	4	4	3
Soil nutrient regime[b]	poor	v. poor	v. poor	rich	v. rich	rich	medium	medium	poor	medium	poor	poor	medium	medium	poor
Slope gradient (%)	8	28	0	20	8	30	27	55	7	18	23	4	13	19	5
Aspect (°)	68	318	N/A	52	82	110	226	96	75	119	130	278	315	335	98
Successional status[c]	MEC	YEC	MEC	MEC	MEC	MCC	MCC	MCC	YCC	MCC	YCC	MEC	MCC	MCC	MC
Structural stage[d]	6	6	6	6	6	7	6	6	5	7	5	6	6	6	7
Stand age (yr)[e]	>186	>70	190	>116	60	>126	>122	125	80	90	152	>105	90	>80	>134
Meso slope position[f]	CR	CR	LV	LW	LW	LW	MD	MD	MD	MD	MD	LV	MD	MD	MD
Soil drainage	v. rapid	rapid	v. rapid	well	mod. well	mod. well	well	rapid	rapid	well	rapid	rapid	well	well	rapid
Root zone particle size[g]	CSI	CLS	F	CLS	FL	CL	CLS	S	S	CLS	SS	S	CLS	CLS	SS
Rooting depth (cm)	18	40	30	72	30	60	55	55	45	45	40	50	40	40	40
Soil great group[h]	HFP	HFP	HFP	DYB	HG	HFP	HFP	DYB	HFP	HFP	DYB	HFP	SB	HFP	DYB
Humus form	Moder	Mull	Mor	Moder	Mull	Moder	Mull	Mull	Moder	Mull	Moder	Mor	Mull	Mull	Moder

a Ranges from 0 (very dry) to 7 (wet); represents the integrated effect of site and soil properties; refers to the relative amount of soil moisture available for plant growth in a subzone.
b Ranges from very poor, poor, medium, rich, to very rich.
c MEC = mature edaphic climax; YEC = young edaphic climax; MCC = mature climatic climax; YCC = young climatic climax.
d 5 = young forest; 6 = mature forest; 7 =old forest.
e The ">" sign indicates that the core sample did not reach pith (e.g., the core was not long enough or the tree was rotten in the centre); therefore, the stand is older than the age reported here.
f CR = crest; LV = level; LW = lower; MD = mid slope.
g CSI = coarse-silty; CLS = coarse-loamy-skeletal; F = fragmental; FL = fine-loamy; CL = coarse-loamy; S = sandy; SS = sandy-skeletal.
h HFP = Humo-Ferric Podzol; DYB = Dystric Brunisol; HG = Humic Gleysol; SB = Sombric Brunisol.

TABLE 4 *Number of pieces, mean diameter, and mean length of coarse woody debris (CWD) by species on the 15 study sites—CDFmm xeric, mesic, and hygric, the CDFmm-CWHxm transitional (TRN) mesic, and the CWHxm mesic sites—presented for each of the south (S), central (C), and north (N) transect sites. Standard deviations are reported (in parentheses) if applicable.*

		CDFmm xeric			CDFmm hygric			CDFmm mesic			CDFmm–CWHxm TRN mesic			CWHxm mesic		
Species[a]	Transect	S	C	N	S	C	N	S	C	N	S	C	N	S	C	N
Fd	No. pieces	1	1	3	2			1	3	4		7	4	7	17	
	Diameter (cm)	9.7	9.0	8.5 (1.3)	10.6 (0.6)			15.0	13.2 (5.3)	20.5 (6.4)		10.7 (1.2)	12.3 (3.8)	25.7 (18.5)	20.4 (1.2)	
	Length (m)	1.0	3.7	4.8 (3.6)	7.4 (6.1)			1.6	9.1 (6.6)	4.3 (5.3)		6.0 (2.4)	12.5 (8.2)	19.5 (14.9)	15.0 (2.4)	
Hw	No. pieces					1	1				4			6		9
	Diameter (cm)					26.3	9.0				24.1 (5.7)			33.3 (13.5)		18.0 (5.4)
	Length (m)					22.7	2.7				15.8 (9.6)			22.7 (11.7)		12.8 (9.6)
Cw	No. pieces				1	2	1			1	3		1			
	Diameter (cm)				18.6	24.8 (15.9)	17.0			30.0	26.3 (14.2)		9.8			
	Length (m)				9.8	5.3 (3.2)	5.6			2.1	13.5 (19.4)		3.9			
Bg	No. pieces				1	1										
	Diameter (cm)				8.0	30.8										
	Length (m)				3.4	13.8										
Dr	No. pieces										1			1		
	Diameter (cm)										19.0			14.7		
	Length (m)										3.6			6.0		
Mb	No. pieces					1			1							
	Diameter (cm)					15.3			15.0							
	Length (m)					11.5			3.7							
Ra	No. pieces								1							
	Diameter (cm)								12.0							
	Length (m)								6.8							
x	No. pieces		2	1	4	3	1	3	5	2	4		6	3	7	7
	Diameter (cm)		16.5		24.0	30.3	36.0	26.6	35.8	21.5	20.9		26.1	19.3	25.2	31.8
			(10.6)		(9.4)	(23.5)		(32.5)	(11.7)	(7.8)	(12.3)		(10.9)	(16.2)	(6.6)	(22.0)
	Length (m)		4.7	5.5	5.0	9.1	3.0	9.6	8.8	3.2	11.2		7.4	13.2	10.4	7.8
			(1.1)		(4.8)	(7.5)		(12.3)	(7.1)	(0.4)	(11.9)		(4.6)	(6.4)	(8.3)	(2.9)

a Fd: Douglas-fir; Hw: western hemlock; Cw: western redcedar; Bg: grand fir; Dr: red alder; Mb: bigleaf maple; Ra: arbutus; x: unknown.

TABLE 5 *Mean diameter at breast height and mean height of trees (standard deviation) in variable-radius plots on the 15 study sites in the CDFmm xeric, mesic, and hygric, the CDFmm–CWHxm transitional (TRN) mesic, and the CWHxm mesic sites, presented for each of the south (S), central (C), and north (N) transect sites*

	CDFmm xeric			CDFmm hygric			CDFmm mesic			CDFmm–CWHxm TRN mesic			CWHxm mesic		
Transect	**S**	**C**	**N**	**S**	**C**	**N**	**S**	**C**	**N**	**S**	**C**	**N**	**S**	**C**	**N**
Diameter (cm)	71.0 (21.0)	36.7 (10.3)	38.4 (14.7)	92.3 (36.7)	82.0 (39.5)	89.9 (41.9)	86.2 (44.7)	73.6 (21.3)	43.7 (17.1)	76.0 (42.6)	50.5 (30.4)	58.7 (26.4)	54.2 (18.6)	41.3 (12.8)	52.8 (18.9)
Height (m)	28.9 (12.4)	24.2 (4.4)	21.1 (5.8)	49.4 (9.5)	37.4 (4.5)	47.0 (7.2)	37.8 (7.0)	44.8 (5.8)	37.0 (7.2)	41.1 (15.7)	31.7 (9.6)	34.4 (5.1)	36.9 (12.8)	31.7 (9.2)	36.2 (5.7)

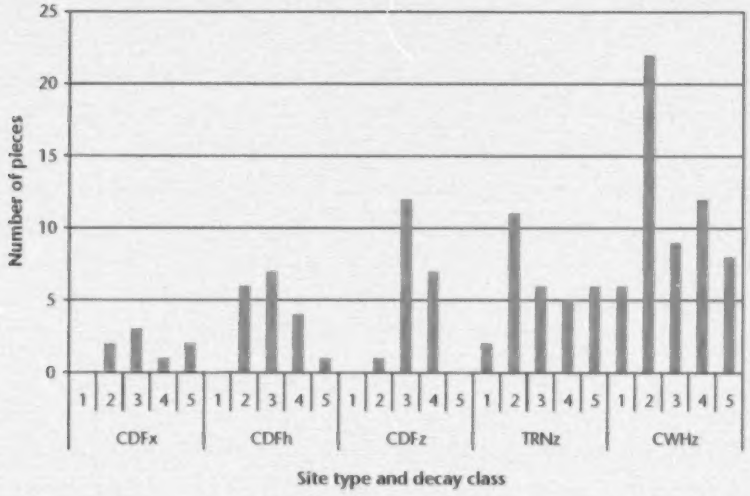

FIGURE 12 *Total number of pieces of coarse woody debris sampled on each site type (all site types pooled across transects) by decay class (CDFmm xeric [CDFx], hygric [CDFh], mesic [CDFz]; CDFmm–CWHxm transitional mesic [TRNz]; CWHxm mesic [CWHz]). Decay class defined primarily by wood texture (1: hard, 2: sapwood rot, 3: advanced decay, 4: extensive decay, and 5: small pieces, soft portions).*

The largest mean tree dbh was recorded on the south transect when comparing subregionally across transects (Table 5). The mean dbh ranged overall from 36.7 cm (CDFmm xeric site on the central transect) to 92.3 cm (CDFmm hygric site on the south transect). Mean tree height was greatest on the CDFmm hygric sites, followed by the mesic and then the xeric sites.

Tree heights on the CDFmm xeric sites were in the lower range of tree heights (0–40 m), whereas on the CDFmm hygric sites, they were in the upper range of tree heights (30–60 m) (Figure 13). Trees on the mesic sites (CDFmm, TRN, and CWHxm) occurred within all height classes (0–60 m). The CDFmm mesic site mensuration plots included only Douglas-fir trees. The other four sites had ≥ two tree species; CWHxm mesic sites had the most species ($N = 4$) (Figure 13).

Douglas-fir was the only species that occurred on all plots. It occurred in the tree stratum on all plots in all site types; in the shrub (regeneration) layer only in the CDFmm xeric sites (all three transects), CDFmm zonal plots (two of three transects), TRN zonal plots (one of three transects), and the CWHxm (one of three transects); and in the seedling layer only in the CDFmm xeric type (one of three transects) (Table 6). The CDFmm zonal and hygric, and the CDFmm–CWHxm transitional zonal site all had a component of deciduous trees in the dominant canopy (stratum A); the highest component occurred on the CDF hygric site (25% bigleaf maple [*Acer macrophyllum*] and 10% red alder [*Alnus rubra*]) on the central transect.

Salal, dull Oregon-grape (*Mahonia nervosa*), and Oregon beaked-moss (*Eurhynchium oreganum*) were common on most sites. Three species were found on all CDFmm xeric sites: baldhip rose (*Rosa gymnocarpa*), rattlesnake plantain (*Goodyera oblongifolia*), and step moss (*Hylocomium splendens*). Western redcedar (*Thuja plicata*) was found on all CDFmm hygric sites in

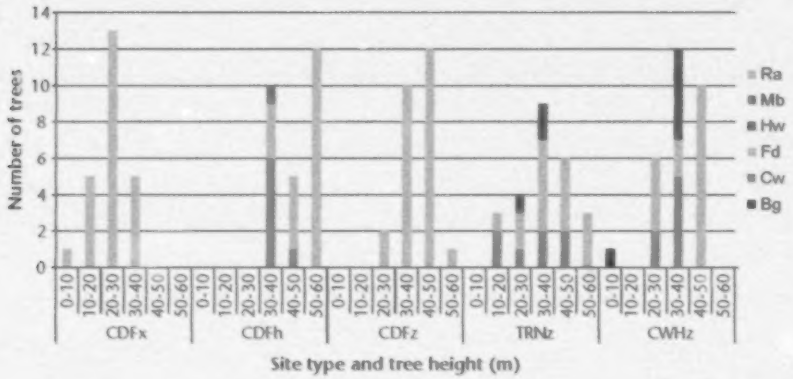

FIGURE 13 *Total number of trees by height class (m) and species [Ra: arbutus; Mb: bigleaf maple; Hw: western hemlock; Fd: Douglas-fir; Cw: western redcedar; and Bg: grand fir] sampled on each site type (all site types pooled across transects) (CDFmm xeric [CDFx], hygric [CDFh], mesic [CDFz]; CDFmm–CWHxm transitional mesic [TRNz]; CWHxm mesic [CWHz]).*

both the A and B strata. Five species were found on all mesic sites (CDFmm, CDFmm–CWHxm transition, and CWHxm): salal, dull Oregon-grape, bracken fern (*Pteridium aquilinum*), broad-leaved starflower (*Trientalis borealis*), and step moss.

A number of species not listed in Table 6 were found on only one CDFmm xeric site and occurred at <0.5% cover, including candystick (*Allotropa virgata*), asters (*Asteraceae* spp.), Vancouver groundcone (*Boschniakia hookeri*), bittercress (*Cardamine* sp.), cladonia lichens (*Cladonia* sp.), few-flowered shootingstar (*Dodecatheon pulchellum*), small-flowered alumroot (*Heuchera micrantha*), Garry oak (*Quercus garryana*), pinesap (*Monotropa hypopithys*), shore pine (*Pinus contorta* var. *contorta*), sea blush (*Plectritis congesta*), Pacific sanicle (*Sanicula crassicaulis*), broad-leaved stonecrop (*Sedum spathulifolium*), and rock-bristle (*Seligeria* sp.)

Mean PPFD was significantly different between xeric and both mesic and hygric sites ($F_{2,24} = 14.05$). In general, within the CDFmm sites, measures of light availability were highest for the xeric sites (Figure 14a). Mean PPFD

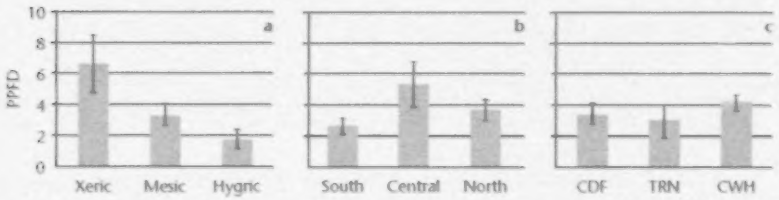

FIGURE 14 *The mean photosynthetic photon flux density (PPFD) for (a) the CDFmm xeric, zonal, and hygric sites (N = 3); (b) sites on the south, central, and north transects (N = 5); and (c) the CDFmm, CDFmm–CWHxm transitional (TRN), and CWHxm mesic sites (N = 3). Standard error bars are shown.*

TABLE 6 *Vegetation descriptions[a] for the 15 study sites—CDFmm xeric, mesic, and hygric, the CDFmm–CWHxm transitional (TRN) mesic, and CWHxm mesic sites—presented for the south (S), central (C), and north (N) transects*

Stratum[b]	Species	Percent of plots with species	Mean cover (%)	CDFmm xeric			CDFmm hygric			CDFmm zonal			CDFmm–CWHxm TRN zonal			CWHxm zonal		
				S	C	N	S	C	N	S	C	N	S	C	N	S	C	N
A	*Acer macrophyllum*	20.0	2.1					25.0			4.0			2.0				
A	*Alnus rubra*	6.7	0.7					10.0										
A	*Arbutus menziesii*	26.7	2.5	10.0	10.0	12.0					6.0							
A	*Pseudotsuga menziesii*	100.0	42.3	22.0	40.0	40.0	78.0	8.0	55.0	60.0	70.0	60.0	25.0	60.0	20.0	50.0	35.0	11.0
A	*Thuja plicata*	53.3	14.7				13.0	40.0	18.0	5.0			50.0		30.0		20.0	45.0
A	*Tsuga heterophylla*	40.0	7.4					5.0			3.0				45.0	5.0	8.0	45.0
B	*Abies grandis*	40.0	0.7		1.0			2.0		3.0	1.0					2.0	1.0	
B	*Acer macrophyllum*	40.0	0.7					2.0	1.0			3.0		1.0		2.0	1.0	
B	*Amelanchier alnifolia*	13.3	0.1							0.1				0.1				
B	*Arbutus menziesii*	13.3	0.2	1.0							2.0							
B	*Gaultheria shallon*	86.7	35.3		4.0	20.0	2.0	1.0		52.0	50.0	75.0	60.0	60.0	20.0	85.0	75.0	25.0
B	*Holodiscus discolor*	33.3	1.8	8.0	11.0					6.0		1.0					1.0	
B	*Ilex aquifolium*	6.7	0.1				1.0	0.1										
B	*Lonicera hispidula*	40.0	0.1	0.1	0.1		0.1				0.1			1.0			1.0	
B	*Mahonia nervosa*	93.3	14.5	0.1	0.1	3.0	3.0	3.0		45.0	50.0	15.0	15.0	20.0	8.0	15.0	15.0	25.0
B	*Pseudotsuga menziesii*	46.7	2.0	6.0	1.0	9.0				3.0	1.0			5.0				5.0
B	*Rhamnus purshiana*	26.7	0.1			0.1						0.5			0.1			0.5
B	*Rosa gymnocarpa*	60.0	0.6	1.0	1.0	1.0				2.0	2.0	0.5		1.0		0.1	1.0	
B	*Rubus spectabilis*	20.0	0.1					0.1	0.1			1.0						
B	*Symphoricarpos albus*	33.3	0.5	0.1	0.1		0.1	0.1		4.0				4.0				
B	*Thuja plicata*	66.7	3.2			4.0	2.0	7.0	6.0			10.0	5.0	1.5	3.0	2.0		8.0
B	*Tsuga heterophylla*	53.3	3.2					2.0	12.0			6.0	4.0	4.0	7.0	5.0	8.0	
B	*Vaccinium parvifolium*	73.3	2.4					2.0	2.0	4.0	3.0	3.0	2.0	2.0	8.0	6.0	2.0	2.0
C	*Achlys triphylla*	53.3	0.8					2.0	0.1		0.1	1.0		2.0	5.0		2.0	0.5
C	*Adenocaulon bicolor*	13.3	0.1									0.1		0.1				
C	*Blechnum spicant*	20.0	0.1	0.1	0.1							1.0						
C	*Carex* sp.	13.3	0.1					0.1									0.1	
C	*Chimaphila umbellata*	20.0	0.2		0.1	0.5										2.0		
C	*Corallorhiza maculata*	13.3	0.1				0.1			0.1								
C	*Dryopteris expansa*	13.3	0.1					1.0	1.0									
C	*Erythronium oregonum*	13.3	0.1	0.1	0.1													
C	*Festuca* sp.	20.0	0.2	0.5		1.0										0.1		
C	*Galium* sp.	46.7	0.2	0.2	0.1		0.5	0.1						0.1			0.1	0.1
C	*Goodyera oblongifolia*	20.0	0.1	0.1	0.1	0.1												

TABLE 6 *Continued*

Stratum[b]	Species	Percent of plots with species	Mean cover (%)	CDFmm xeric			CDFmm hygric			CDFmm zonal			CDFmm–CWHxm TRN zonal			CWHxm zonal		
				S	C	N	S	C	N	S	C	N	S	C	N	S	C	N
C	Grass spp.	33.3	0.1	0.1	1.3	0.1	0.1	0.1						0.1			0.1	
C	*Hieracium* sp.	13.3	0.1	0.1		1.0												
C	*Lactuca muralis*	13.3	0.1				0.5							0.1				
C	*Linnaea borealis*	13.3	0.7			2.0										8.0		
C	*Luzula* sp.	13.3	0.3	0.5	0.1													
C	*Melica subulata*	40.0	0.4	5.0	0.1								0.1	0.1	0.1	1.0		
C	*Polygonum minimum*	6.7	0.3														5.0	
C	*Polystichum munitum*	80.0	13.2	0.5	2.0		10.0	70.0	85.0	1.0	1.0	3.0	12.0	5.0		5.0		4.0
C	*Pteridium aquilinum*	66.7	2.0						1.0	0.1	0.1	5.0	1.0	10.0	6.0	1.0	5.0	1.0
C	*Rubus ursinus*	60.0	0.4				0.1	0.1	1.0	0.5	0.1	2.0		2.0		0.1	1.0	
C	*Rumex acetosa*	13.3	0.1	0.1	0.1													
C	*Trientalis borealis*	66.7	0.1		0.1		1.0	0.2	0.1		0.1	0.1	0.1	1.0	0.1	0.1	0.1	0.5
D	*Acer macrophyllum*	13.3	0.1				1.0											0.1
D	*Dicranum fuscescens*	13.3	3.0	0.1	45.0													
D	*Eurhynchium oreganum*	100.0	18.3	1.0	5.0	45.0	25.0	1.0	5.0	23.0	5.0	3.0	80.0	20.0	10.0	40.0	6.0	5.0
D	*Eurhynchium praelongum*	20.0	0.2						0.5				1.0			1.0		
D	*Hylocomium splendens*	80.0	21.9	4.0	45.0	5.0			15.0	2.0		80.0	10.0	5.0	80.0	55.0	3.0	25.0
D	*Leucolepis acanthoneuron*	13.3	0.2				1.0	2.0										
D	*Plagiothecium undulatum*	20.0	0.2		0.1										2.0			1.0
D	*Pleurozium schreberi*	6.7	3.0			45.0												
D	*Polytrichum commune*	6.7	0.1	0.1	2.0													
D	*Polytrichum juniperinum*	6.7	0.3		5.0													
D	*Rhytidiadelphus loreus*	26.7	0.9									2.0		10.0			1.0	0.1
D	*Rhytidiadelphus triquetrus*	20.0	6.5	90.0										0.1		8.0		
D	*Rhytidiopsis robusta*	13.3	0.3		2.0								3.0					

a Species presented in this table occur in > one plot or one plot with > 5% cover.
b A: tree, B: shrub, C: herb, and D: moss/lichen/seedling.

was significantly different between the south and central transects but not between the south and north transects or the central and north transects ($F_{2,24} = 4.65$). Mean PPFD was highest on the central transect and lowest on the south transect (Figure 14b). Mean PPFD did not differ significantly among mesic sites (CDF, TRN, CWH) (Figure 14c).

4.2.1 Microclimate Mean annual air temperature on the south transect CDFmm mesic site (forested site) was 0.5°C lower than that at the Victoria climate station (open site), although variation around the means of these two locations was similar (Figure 15). Mean annual precipitation was 397 mm less on the CDFmm mesic site than at the airport (Figure 15), which illustrates the potential for the tree canopy to intercept precipitation on a forested site. It also suggests the potential impact of missing data (missing $N = 132$ days in year 2 of the project).

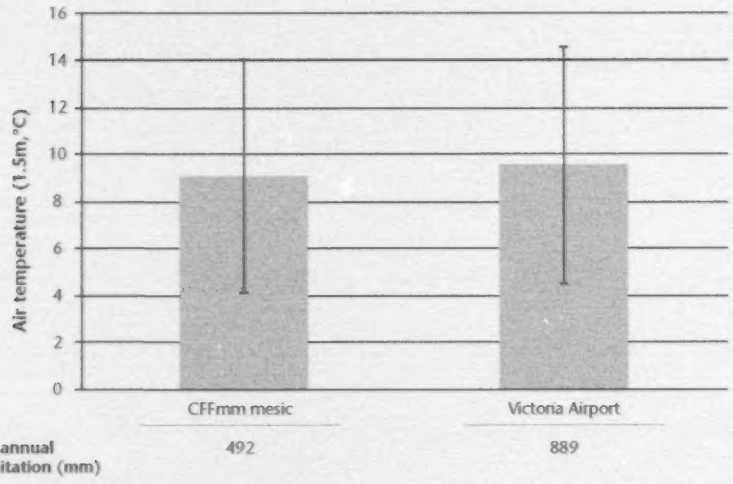

FIGURE 15 *Mean annual air temperature for the south transect CDFmm mesic site and the Victoria Airport climate station (Government of Canada 2014) for the June 1, 2010–May 31, 2013 sampling period. The error bars are standard deviations. The mean annual precipitation for the 2010–2013 sampling period is below the bar chart.*

The mean daily air and soil temperatures and the soil moisture levels from the south transect CDFmm xeric (Figure 15a) and CDFmm hygric (Figure 15b) sites were compared to illustrate the seasonal trends and relative differences in central tendencies and variability of microclimate variables. Mean daily air temperature and soil temperature patterns were similar on the south transect xeric and hygric sites. However, soil temperature was generally greater than air temperature during the fall and winter, and was lower during summer. The soil was near saturation during the fall and winter on both sites, and soil moisture decreased gradually during the growing season. Soil moisture fluctuated more on the xeric site (0–42%) than on the hygric site (0–20%).

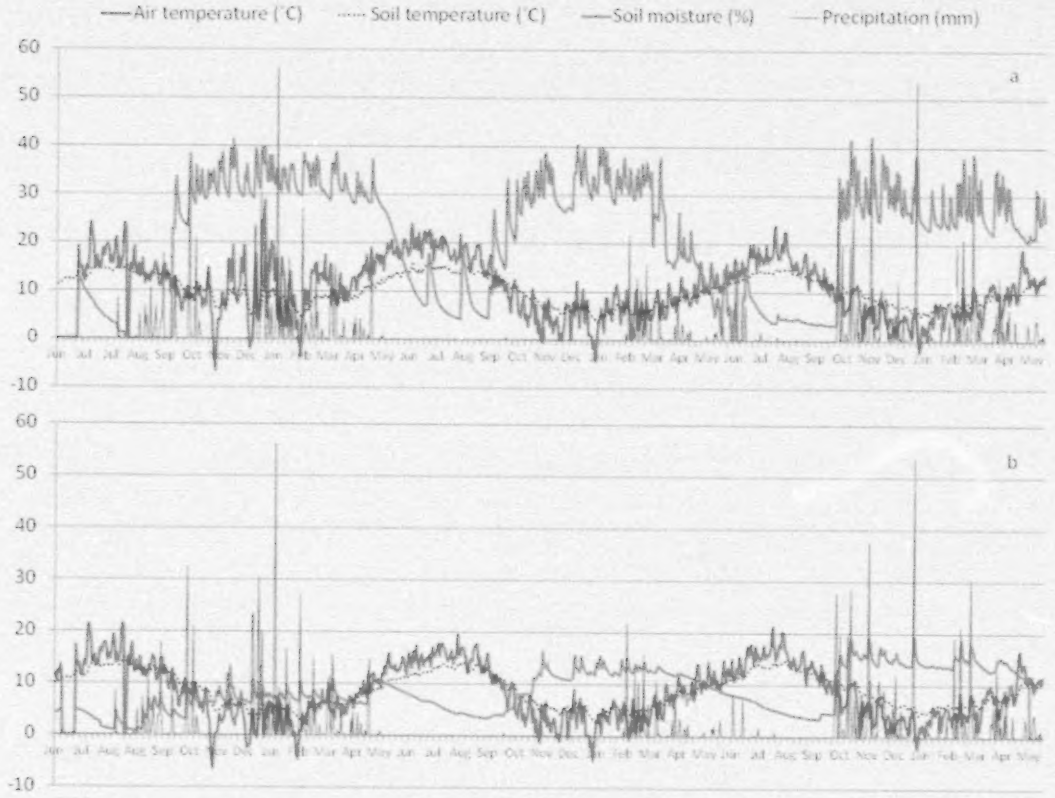

FIGURE 16 *Mean daily air temperature at 1.5 m above ground surface, soil temperature at 0.3 m below ground surface, soil moisture at 0.3 m below ground surface, and total daily precipitation time series from June 1, 2010 to May 31, 2013. The temperature and moisture values are from the (a) CDFmm xeric site south transect, and (b) CDFmm hygric site south transect; the precipitation values are from the CDFmm mesic site south transect.*

Trends in microclimate across sites and transects differed among variables during the June 1, 2010–May 31, 2013 sampling period (Table 7). Air and soil temperatures were highest on the xeric sites (annual means for all xeric sites were 11.1°C and 10.3°C, respectively). The mean soil moisture content was highest in the hygric sites of the central and north transects, and the xeric site on the south transect. Xeric and hygric sites were most variable in mean annual soil moisture across all transects relative to the mesic sites of the CDFmm, CWHxm, or CDFmm–CWHxm transition (e.g., soil moisture on the central transect CDFmm xeric = 17.3% [±7.8 SD], hygric = 22.7% [±9.1 SD], and mesic = 9.2% [±3.8 SD]).

Precipitation and relative humidity were highest on the CWH zonal sites for all transects (mean annual precipitation = 858.6 mm and relative humidity = 91.7%). Wind speed measures were ≤ 0.3 m/s on all sites. Solar radiation measures were highest on the south transect and decreased from the central to the north transect (Table 7).

Mean daily air temperature on the north transect was higher (9.5°C) than that on the central (8.7°C) and south (8.9°C) transects; the central transect

TABLE 7 *Mean annual microclimate measures (standard deviation in parentheses) for the 15 study sites—CDFmm xeric, hygric, and mesic, CDFmm–CWHxm transitional (TRN) mesic, and CWHxm mesic sites on the south, central, and north transects from June 1, 2010 to May 31, 2013. Precipitation, relative humidity (RH), wind speed, and solar radiation were sampled only on the mesic sites; CDFmm and CWHxm mesic site results are presented here because these sites were sampled for the duration of the 2010–2013 sampling period.*

Transect	Site	Air temp. 1.5 m (°C)	Air temp. 0.3 m (°C)	Soil temp.[a] (°C)	Soil moisture[a] (%)	Precip. (mm)	RH (%)	Wind speed (m/s)	Solar radiation (w/m²)
South	CDFmm xeric	11.0 (4.8)	11.0 (4.8)	10.2 (2.9)	21.7 (10.6)				
	CDFmm hygric	8.6 (5.0)	8.6 (5.0)	8.9 (3.1)	8.9 (3.2)				
	CDFmm mesic	9.1 (5.0)	8.9 (5.0)	9.4 (3.5)	11.9 (4.0)	491.5 (309.0)	87.2 (9.6)	0.2 (0.1)	347.7 (272.5)
	TRN mesic	7.7 (5.4)	7.7 (5.3)	7.6 (3.3)	11.6 (3.8)				
	CWHxm mesic	8.3 (5.4)	8.0 (5.3)	8.7 (3.0)	10.4 (2.1)	893.1 (262.2)	92.8 (8.1)	0.0 (0.0)	413.7 (323.0)
Central	CDFmm xeric	9.8 (5.0)	9.7 (5.0)	9.8 (3.2)	17.3 (7.8)				
	CDFmm hygric	6.8 (4.7)	6.9 (4.7)	7.4 (2.7)	22.7 (9.1)				
	CDFmm mesic	9.7 (5.7)	9.4 (5.6)	9.2 (3.8)	9.2 (3.8)	478.3 (65.8)	84.8 (10.0)	0.3 (0.1)	268.7 (203.3)
	TRN mesic	9.1 (5.7)	9.1 (5.5)	9.0 (4.1)	7.9 (2.6)				
	CWHxm mesic	8.2 (5.7)	8.0 (5.7)	7.8 (3.8)	11.2 (3.0)	821.8 (453.9)	89.9 (9.2)	0.1 (0.1)	252.5 (208.9)
North	CDFmm xeric	12.4 (4.5)	12.3 (4.5)	10.9 (3.6)	8.2 (3.5)				
	CDFmm hygric	8.5 (5.0)	8.5 (4.8)	8.7 (3.2)	22.6 (5.8)				
	CDFmm mesic	8.8 (5.0)	8.1 (5.1)	9.0 (3.2)	11.4 (4.5)	790.8 (53.2)	89.0 (7.6)	0.2 (0.1)	207.0 (167.4)
	TRN mesic	9.4 (5.3)	9.5 (5.3)	9.2 (3.4)	11.3 (5.0)				
	CWHxm mesic	8.4 (5.3)	8.5 (5.4)	8.4 (3.6)	10.9 (2.6)	860.8 (65.2)	92.5 (7.0)	0.1 (0.1)	194.0 (144.5)

a Soil temperature and moisture were sampled at 27.5 cm below ground surface. Mean values are based on three samples per site.

had the largest range in temperatures (Figure 17). Mean daily soil moisture on the south and north transects was less (12.9% for both sites) than that on the central transect (13.7%); the central transect had the greatest range in soil moisture.

The mean daily air temperature and mean daily soil moisture in each of the five site types were compared (Figure 18). The xeric sites had the warmest air temperatures (11.1°C); the hygric sites had the coolest (8.0°C). Mean daily air temperature decreased from the CDFmm (9.2°C) to the CDFmm–

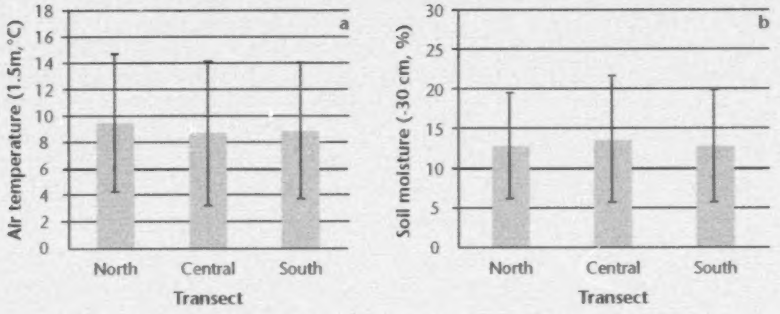

FIGURE 17 *(a) Mean daily air temperature and (b) mean daily soil moisture for the north, central, and south transects. Data are the mean daily values for the five sites per transect from June 1, 2010 to May 31, 2013 (N = 5 475 days). Standard error bars are shown.*

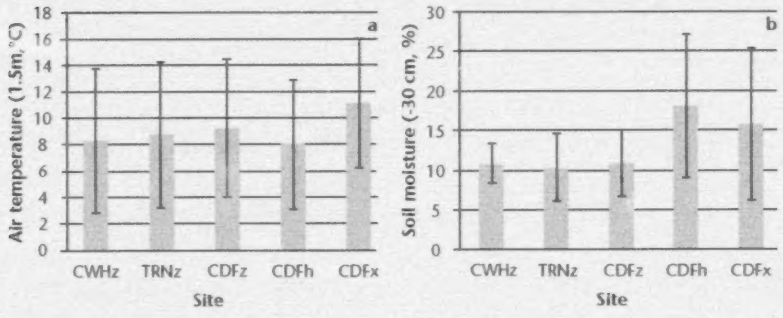

FIGURE 18 *(a) Mean daily air temperature and (b) mean daily soil moisture for the CDFmm, CDFmm–CWHxm transitional (TRN), and CWHxm zonal (z) sites and the CDFmm hygric (h) and xeric (x) sites. Data are the mean daily values for the 2010–2013 period for all three transects combined (N = 1 095 days). Standard error bars are shown.*

CWHxm transition (8.7°C) and CWHxm zonal sites (8.3°C). Generally, mean soil moisture was highest on the hygric sites in the CDFmm (18.0%); among zonal sites, mean soil moisture was highest on the CWHxm sites (10.8%).

The dry season (implying the potential for a moisture deficit) commenced in May in the CDFmm and continued until the end of September; in the CWHxm, it began in early June and continued to late August (Figure 19). Precipitation was higher in the CWHxm than in the CDFmm, which resulted in a longer wet season (implying a water surplus). In both the CDFmm and CWHxm sites, sub-zero air temperatures occurred from November through April. Maximum and minimum monthly temperatures were most extreme in the CWHxm mesic sites.

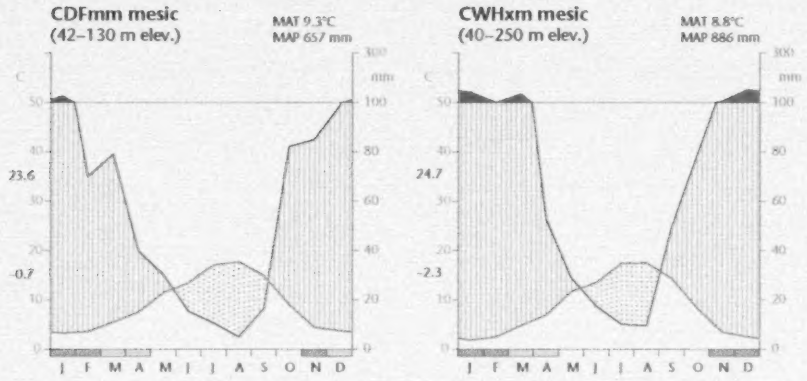

FIGURE 19 *Walter and Lieth climatic diagram for the CDFmm and CWHxm zonal sites for the June 1, 2010–May 31, 2013 sampling period. Blue = total monthly precipitation (right side of the y-axis); red = mean monthly air temperature at 1.5 m above the ground (left side of the y-axis). The dry season (red dotted area) occurs when the precipitation curve undercuts the temperature curve; the moist season (blue vertical lines) occurs when the precipitation curve supersedes the temperature curve; the solid blue area denotes a wet period. The grey bars below the x-axis indicate potential frost period. The mean annual temperature (MAT) and mean annual precipitation (MAP) are noted on the top right; the maximum and minimum monthly temperature is noted on the left of each figure.*

4.2.2 Tree growth Coastal Douglas-fir chronologies for the five sites on the south transect showed generally similar patterns over the last century (Figure 20). There were some noticeable similarities among chronologies. Low annual growth occurred in 1911, 1912, 1930, 1979, 1982, 1985, 1989, 1999, 2004, and 2007; relatively high annual growth occurred in 1946, 1948, and 1997. Annual growth declined on average by 48.4% (± 4.8 SE) between 1981 and 2009 on all sites.

Stands on the xeric site had some pronounced growth patterns relative to stands on the other sites. For example, in 1930, xeric site stands had a noticeably greater growth decline than did stands on other sites, but in 1997, they had a noticeably higher growth response than did other stands.

Preliminary results suggest that drought and summer precipitation are the primary climatic variables that limit tree growth across the south transect. Sensitivity to drought was highest in the xeric site in the CDFmm: since approximately 1980, summer precipitation has generally declined and growth has become highly sensitive to summer precipitation ($r^2 = 0.46$) (Figure 21).

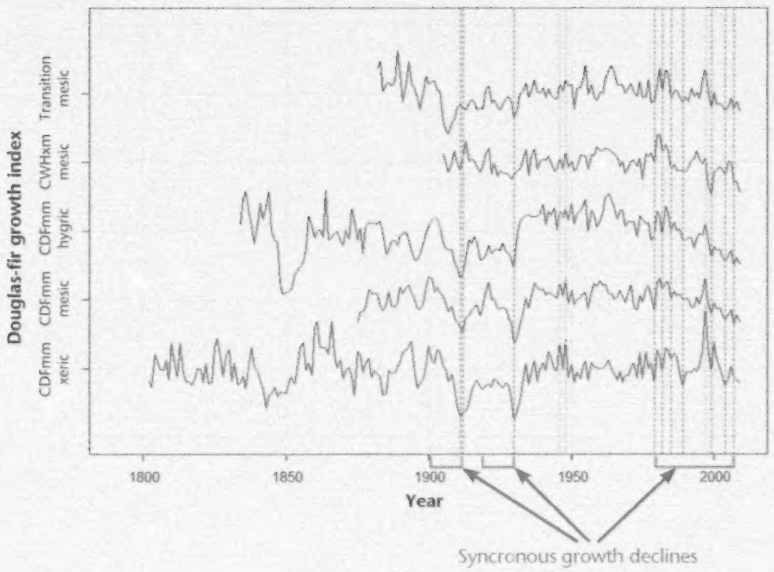

FIGURE 20 *Annual growth of Douglas-fir (*Pseudotsuga menziesii*) at the five study sites on the south transect. Growth index is a standardized deviation of the mean growth for the stand. Horizontal lines for each site type indicate mean growth rate (standardized to a value of 1.0) for the stand at this site over the period depicted; values above or below these lines represent proportion deviations from the mean growth rate during this period. Vertical red lines indicate years with relatively low growth; green lines indicate years with relatively high growth within the examined time period.*

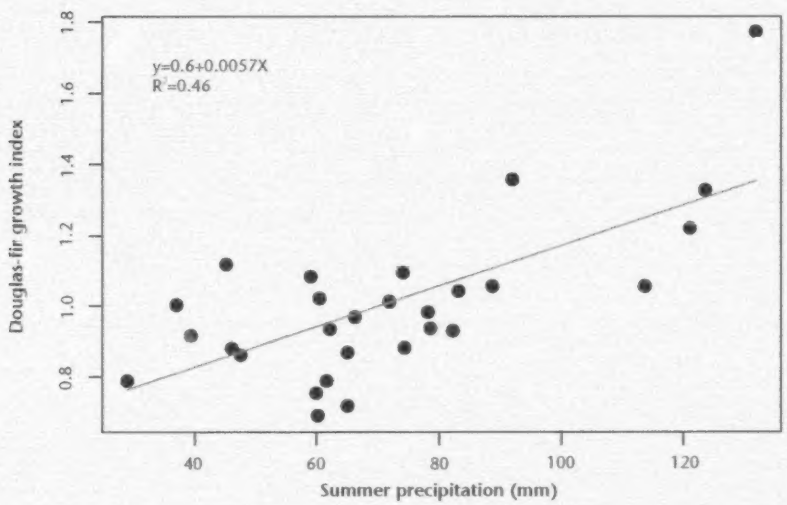

FIGURE 21 *Relationship between average annual growth of overstorey Douglas-fir trees and summer precipitation (Victoria Airport climate station [Government of Canada 2014]) on the south transect CDFmm xeric site over 30 years (1980–2009).*

4.2.3 Decomposition rates Within the CDFmm, decomposition sticks deployed in the F soil horizon had the highest mass loss rates overall, particularly in the hygric site. There was a weak trend of increasing total mass loss from xeric sites to hygric sites. This trend was most apparent in the B horizon (Figure 22).

Comparison of regional climate influences on decomposition (i.e., mesic or zonal sites) indicated that total mass loss decreased from the CDFmm sites to the TRN sites, and increased again in the CWHxm for both the L and F soil horizons (results not shown). However, in the B horizon, decomposition increased from the CDFmm xeric sites through the CDFmm zonal and hygric sites to the TRN zonal sites and again in the CWHxm zonal sites (Figure 23).

Mass loss of decomposition sticks in the B soil horizon across site types was most strongly negatively correlated to annual (and fall) soil temperatures (r = -0.91) (Figure 24a) and was positively correlated to fall soil moisture when examining site types across all transects (Figure 24b); however, the CDFmm xeric site was an outlier with respect to soil moisture values (r = 0.90 excluding the xeric site; r = -0.91 with the xeric site).

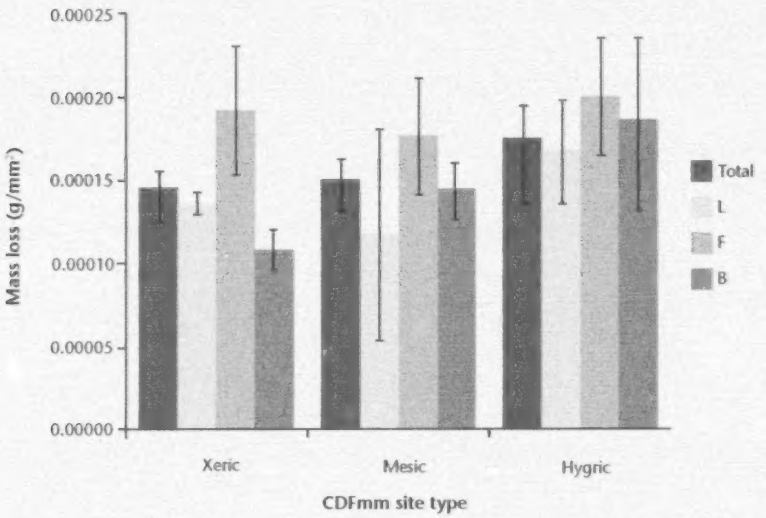

FIGURE 22 *Mass loss of decomposition sticks deployed in the L, F, and B soil horizons, and in total at xeric, mesic, and hygric sites of the CDFmm. Data are averages for three transects (south, central, north); standard error bars are shown.*

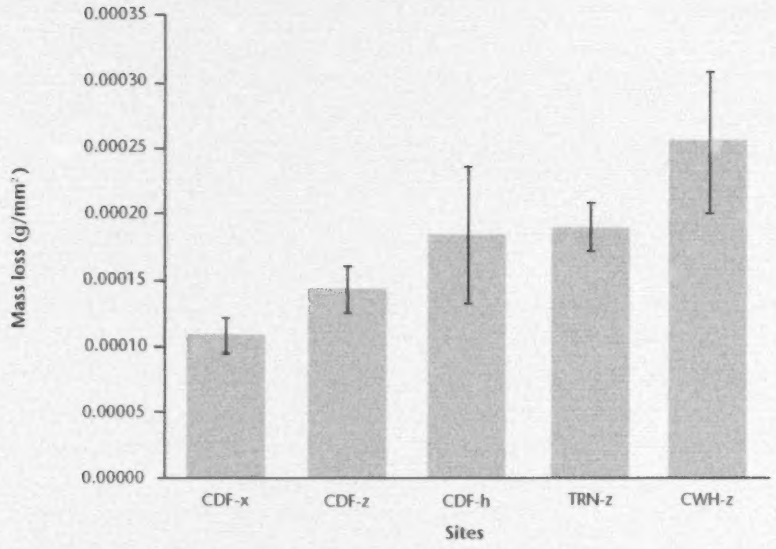

FIGURE 23 *Mass loss of decomposition sticks deployed in the B soil horizon across the three site types of the CDFmm (CDF), and mesic sites of the CDFmm–CWHxm transition (TRN) and CWHxm (CWH). Data are averages for three transects (south, central, and north); standard error bars are shown.*

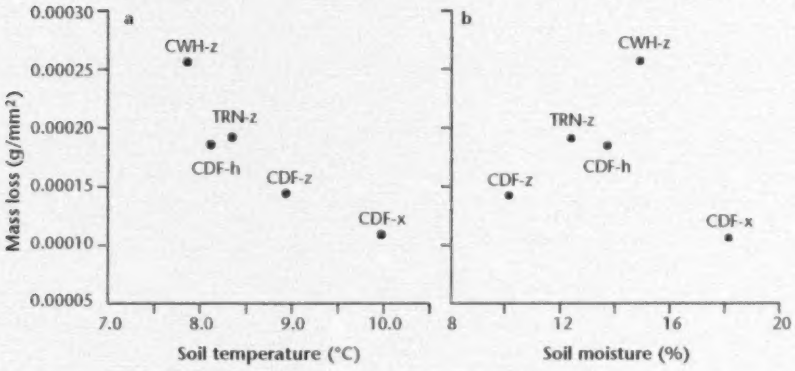

FIGURE 24 *Relationship of mass loss of decomposition sticks in the B soil horizon to (a) average annual soil temperature, and (b) fall soil moisture at 25–30 cm depth. Values for mass loss (decomposition) are averages for three study locations representing each site type on southeastern Vancouver Island.*

4.2.4 Salal biomass and dynamics Site type (xeric, zonal, hygric) significantly affected salal foliar attributes and productivity in the CDFmm (Table 8). Total salal biomass and current year's production peaked on mesic sites, followed by hygric sites and then xeric sites. Foliar attributes were characterized by increasing leaf area and nitrogen concentrations and declining tannin concentrations (Table 8) from xeric to zonal to hygric moisture regimes. Litter quality (Tannin:N ratio), as a result, was strongly affected by site. Poorest litter quality occurred on the xeric sites; highest litter quality occurred on the hygric sites (Table 8).

TABLE 8 *Salal foliar attributes and biomass (average stem biomass and current year's growth) across three transects in the CDFmm (N = 9 plots). The last row indicates significance of a 1-way ANOVA for differences in means among the three site types for the variable in the column*

Site type	Nitrogen[a] (N) (%)	Tannin[a] (%)	Litter quality[a] (Tannin:N)	Leaf mass (g)	Leaf area (cm^2)	Stem biomass (g)	Current year's biomass (g)
Xeric	0.90	15.4	1.75	0.26	27	3.60	1.3
Zonal	0.91	10.6	1.16	0.43	48	37.10	7.25
Hygric	1.14	6.7	0.60	0.36	55	17.10	3.91
Pr > F	0.018	<0.001	0.002	0.004	<0.001	<0.001	0.028

a $N = 15$ leaves per plot.

In contrast, the effects of climate (zonal sites only) on foliar nitrogen and tannin concentrations were statistically non-significant (Table 9). Stronger correlations were found with salal productivity and leaf size, as demonstrated by the decline in current year's shoot biomass and leaf mass with increasing mean annual precipitation (Figure 25).

TABLE 9 *Results of simple linear regression (p values) of salal foliar attributes and biomass against climate variables for zonal (mesic) sites of the CDFmm, adjacent CWHxm, and geographic transition between the two (N = 9 sites); r^2 provided where $p < 0.05$*

	Mean annual temperature (°C)	Mean annual precipitation (mm)	Annual heat moisture index[a]
Nitrogen (N) (%)	0.907	0.306	0.372
Tannin (%)	0.940	0.154	0.306
Quality (Tannin:N)	0.953	0.130	0.263
Leaf mass (g)	0.165	0.006, $r^2 = 0.64$	0.009, $r^2 = 0.60$
Leaf area (cm^2)	0.181	0.018, $r^2 = 0.52$	0.022, $r^2 = 0.49$
Stem biomass (g)	0.284	0.036, $r^2 = 0.49$	0.036, $r^2 = 0.49$
Current shoot biomass (g)	0.197	0.025, $r^2 = 0.53$	0.027, $r^2 = 0.53$

a Wang et al. (2010).

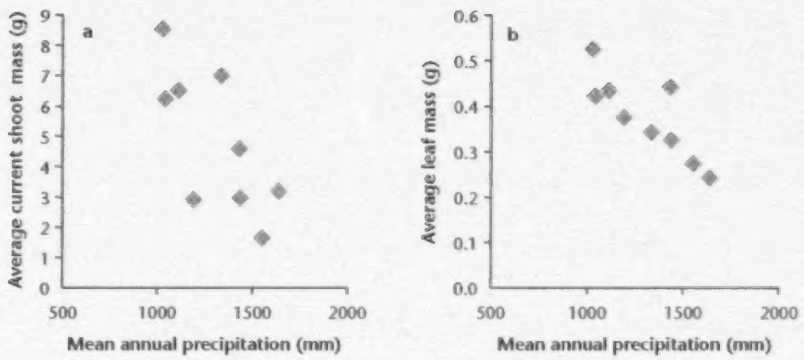

FIGURE 25 *Relationship of (a) average current salal shoot (stem with leaves and berries) biomass, and (b) average salal leaf biomass to mean annual precipitation at mesic sites of the CDFmm, CDFmm–CWHxm transition, and CWHxm.*

The correlation between salal productivity (shoot biomass) and leaf mass over all plots was highly significant (Figure 26a); the relationship of productivity to foliar nitrogen concentration was not statistically significant (Figure 26b).

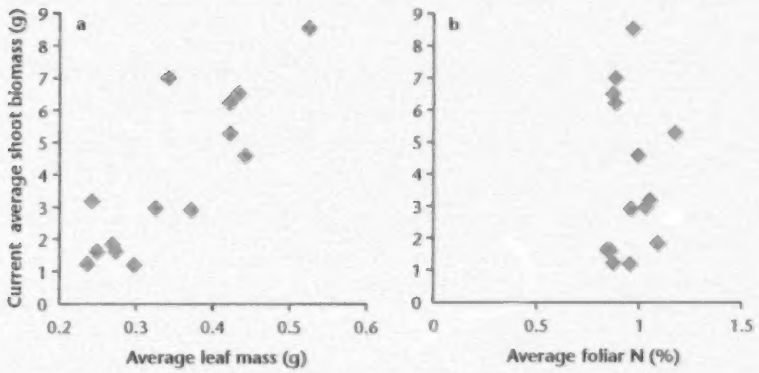

FIGURE 26 *Relationship of current year salal productivity (current year shoot biomass) with (a) average leaf mass ($p<0.001$, $r^2=0.71$), and (b) average foliar nitrogen (N) concentration.*

Trends in initial numbers of salal stems were similar across transects, and trends in regeneration and maintenance of stems were consistent among site types of the central and north transects. CDFmm xeric sites had the highest average number of stems per clip plot on a transect. Stems per plot decreased in the CDFmm mesic and hygric sites, but increased again in the TRN mesic and CWHxm mesic sites (Figure 27). Regeneration of stems, relative to initial

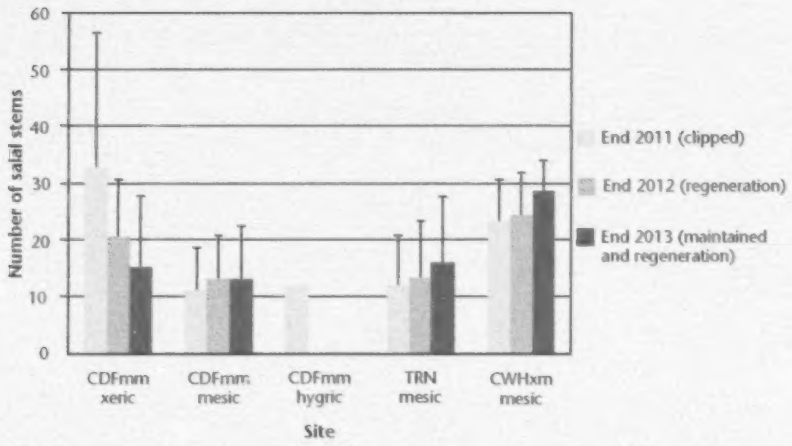

FIGURE 27 *Salal dynamics in the CDFmm, CDFmm–CWHxm transitional (TRN) mesic, and CWHxm mesic sites on the central transect, including the initial number of stems clipped (end 2011), regenerated stems surviving 1 year post clip (end 2012), and maintained and regenerated stems surviving 2 years post clip (end 2013). Bars show the average (with standard deviation) number of stems from three 1 × 1 m plots per site.*

numbers, was highest in the TRN and CWHxm mesic sites; post clip increases in stems were minimal in the CDFmm zonal sites, and stem numbers dropped post clip in both xeric and hygric sites of the CDFmm (Figure 27).

4.2.5 Ecosystem nutrient status The average concentrations of amino acids, ammonia, and nitrate (mg/kg soil) extracted after the 8-week incubation period demonstrated strong patterns along the productivity gradient (as defined by Douglas-fir site index), where each nitrogen type was progressively replaced in dominance (Figure 28a). When converted to mass (kg/ha), the quantity of extractable nitrogen (organic and inorganic nitrogen combined) as an index of soil nitrogen supply was positively associated with Douglas-fir site index ($p = 0.001$, $r^2 = 0.56$).

Current wood $\delta^{15}N$ was positively, but weakly, correlated with site index (Figure 28b; $p = 0.010$, $r^2 = 0.41$); a stronger relationship was found using a multiple linear regression to account for variation in soil $\delta^{15}N$ (Figure 28b). The combined trend in wood $\delta^{15}N$ values from 1900 to 2009 was negative, with a net decline of 0.9‰, but the patterns diverged widely among plots. Residual $\delta^{15}N$ was significantly correlated ($p < 0.10$) with residual mean annual temperature in only one of the 15 plots.

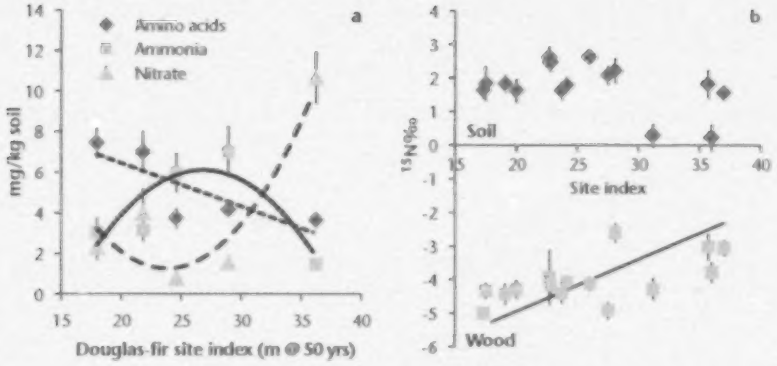

FIGURE 28 *(a) Gross production of amino acids, ammonia, and nitrate along the productivity gradient of Douglas-fir (each point is an average of the three replicates for each plant association; bars represent ± SE). (b) Soil $\delta^{15}N$ (0–15 cm) and current wood increment $\delta^{15}N$ (bars ± SE) for each plot in relation to Douglas-fir site index; the multiple linear regression (SI50 = 59.3 + 6.46[ring $\delta^{15}N$] – 4.21[soil $\delta^{15}N$]; p=0.004, r^2=0.61) was plotted with soil $\delta^{15}N$ = 1.75.*

5 APPLICATION OF DATA TO CURRENT AND FUTURE STUDIES

Ecosystem resilience refers to the amount of perturbation an ecosystem can absorb or resist before changes in structure, function, or composition produce an altered ecosystem state. Although ecosystems have an inherent level of resilience, cumulative pressures of resource extraction and projected climate change may result in ecological shifts at various spatial and temporal scales (Campbell et al. 2009). The integrated ecological studies discussed in this report, which are stratified across a range of site conditions (soil moisture and nutrient status) and BEC subzones (regional climate), are designed to:

- quantify climate–site–vegetation relationships to enhance understanding of the dynamics of complex systems, and of the sensitivity analysis of ecosystem and landscape-level models of resilience
- present a basis for testable hypotheses and predictions about the nature of potential change in these ecosystems due to cumulative stresses at site and subregional scales
- provide initial recommendations about attributes that can be measured and monitored in the field as indicators of climate shift and system changes that are driven by new climate conditions.

The initial results from the subprojects discussed in this report will help refine and prioritize subsequent research on predicting and validating impacts of climate change in this highly modified landscape.

The variability of subregional climate across the latitudinal extent of the study area, of microclimate across site types, and of the relationships between macroclimate and microclimate, illustrate the impacts of vegetation and terrain on heat and moisture transfer within the forested environment. The

CDFmm and CWHxm mesic site microclimate data support published concepts of differentiations between CDFmm and CWHxm climates (Meidinger and Pojar 1991). However, these data illustrate that changes in microclimatic conditions due to regional climate change will vary with spatial scales and differ at even relatively fine (e.g., site) scales; they also suggest that further analyses across geographic extent (regional, subregional, and site) and time periods (e.g., annual, seasonal, monthly) are required. Current analyses focus on interannual variability in soil water balance and comparisons across gradients of mesoclimate (subzones) and relative soil moisture regime (site types).

Analysis of Douglas-fir tree growth demonstrated site–climate relationships on the south transect. Generally, diameter growth has declined since 1981, though the trend is most pronounced on the CDF hygric site. Consistency of this growth pattern across site types suggests that climate is a primary driver of productivity at the subregional scale. Increased temperatures in the Pacific Northwest (Mote 2003) and more extreme moisture limitations during the growing season may be causing a change in growth response to climate or increasing maladaptation of Douglas-fir populations (Spittlehouse 2003). At the site level, the results were similar to findings in the interior of British Columbia and the Yukon, where dry sites also show a relatively high sensitivity to climate, particularly precipitation inputs (Miyamoto et al. 2010; Griesbauer et al. 2011). Further analyses of the climate-related tree growth patterns are being conducted to determine subregional relationships (south, central, and north transects) and to develop hypotheses about thresholds of moisture stress at which climate–site relationships may be altered and thus potentially drive a shift in overstorey structure.

Although there was a weak trend of increasing decomposition rate (fine woody debris) in the B soil horizon from xeric to hygric sites, the high soil moisture measured at the CDFmm xeric site was an outlier in the decomposition–soil moisture relationship, which confounded interpretation of regional climate vs. site-level impacts on the decomposition process. Similarly, the strong negative relationship between mass loss and soil temperature was contrary to expectations based on the current literature (e.g., Prescott 2005a; Aerts 2006; Zhang et al. 2008), and may have been due to confounding factors, such as moisture, that vary with temperature (Prescott 2005a). The intention was to use standardized materials to remove the influence of litter quality and isolate effects of climate on linkages between decomposition rates, available soil nutrients, and vegetation productivity. However, litter quality may be more critical and effective as a tool for determining the relative rate of decay within a regional climate (Prescott 2005a). Furthermore, direct measurements of the decomposer community (e.g., fungal vs. invertebrate) and/or rates of microbial activity may be more effective indicators of processes that integrate the effects of climate (change) and litter quality on available nutrients.[17] Alternatively, total mass and nutrient content of litter input may provide a stronger indicator (than process rates) of ecosystem productivity (Prescott 2005b), and parsimony may argue for monitoring vegeta-

17 Collaborative work on mesic sites across all transects is being conducted with researchers at the University of Victoria and the Canadian Forest Service, and involves evaluating the nature of soil microbial functional groups, litter-associated fungi, climate, and litter chemistry and their role in fine litter decomposition.

tion (understorey) production or foliar nutrient content over soil chemistry. The results to date suggest that even a subsample of the current year's growth could be substituted for more invasive clip plots in assessing productivity and could provide a strong link to annual temperature, precipitation, and associated nutrient availability across site types and subregional macroclimates.

The relationship between site productivity and current wood $\delta^{15}N$ of Douglas-fir was consistent with positive correlations for foliar $\delta^{15}N$ of understorey species across a similar edaphic (moisture and nutrient) gradient in boreal forests (Kranabetter and MacKenzie 2010), and confirmed the potential utility of this index in monitoring nitrogen dynamics across landscapes. Incorporation of small variations in soil $\delta^{15}N$ across site types improved the predictive relationship between tree site index and current wood nitrogen. However, the interactions between site- and regional-level (climatic) influences on this association are indeterminate based on these initial results. The lack of correlation of residual wood $\delta^{15}N$ (and thus site productivity) to annual climatic variables among plots, despite the large interannual fluctuations in mean annual temperature and mean annual precipitation,[18] contrasted with the relatively strong associations between current understorey productivity (leaf and shoot biomass) and climate (e.g., annual precipitation). Low climate–residual wood $\delta^{15}N$ correlations may be due partly to limitations in methodology but may also reflect the relative stability in nitrogen supply over the previous century due to the overriding constraints of soil organic matter quantity and quality. Upcoming chronosequence studies in the CWHxm will clarify whether wood $\delta^{15}N$ can accurately portray temporal ecosystem nitrogen status, and whether, at this local scale, wood N, site index, or diameter growth still provide a field indicator of climatic thresholds at which overstorey structure will begin to shift to alternative states.

The results to date suggest that effective indicators of shifts in climate and the implications for the structure and function of dry south coast forests vary with both temporal and spatial scales. Some processes, such as understorey productivity and mineral horizon decomposition rates, relate consistently to microclimate and macroclimate across sites over short temporal scales. Other processes, such as overstorey site index, relate strongly to site nutrients but cannot be clearly associated with climate at the spatial scale of this project. Comparative studies among subregions will be continued in order to quantitatively evaluate similarity of climate–process relationships spatially (e.g., Douglas-fir productivity on the central and north transects). Temporal consistency of relationships—for example, between current year's salal leaf biomass and site condition—must also be examined in order to make recommendations on field indicators of climate change and ecosystem shifts.

Most critically, the quantitative mechanistic relationships developed during the project can now be used to generate and test predictions of species productivity and community composition in current landscapes and with shifts in regional and site-level climate. Continued sampling will be targeted to refine parameterization of these predictive models. For example, relationships of primary productivity to water balance, which represents growing conditions (e.g., soil moisture deficits), are being developed to generate hypotheses about shifts in relative productivity of species and resultant

18 Only three of the 15 plots used in the ecosystem nutrient study were common to the other subprojects, although all 15 of these plots were within the south transect subregion.

community transformations. The associated ongoing field measurements are critical for calibrating the water balance models and increasing confidence in quantification of climate–soil–vegetation feedbacks, which can vary across site conditions (Oke 1987; Ehrenfeld et al. 2005) and time (Detto et al. 2006). Additionally, field experimentation has been initiated to manipulate climate conditions and provide a more controlled environment for identifying climatic thresholds that force change in productivity and growth relationships over short temporal scales. Both passive and active climate manipulation have been used to assess climate shift impacts on processes as varied as vegetation productivity (e.g., Haider et al. 2012), nutrient cycling (Rustad et al. 2001), and arthropod dispersal (Pelini et al. 2011); however, evaluation of passive mechanisms within closed canopy conditions is relatively novel.

Forest ecosystems in many parts of the world are experiencing changes in climate, with global air temperatures increasing by 0.8°C (0.35°C per decade in the northern hemisphere since 1970) and precipitation increasing by 3–5% over the last century (Boisvenue and Running 2006; Christensen et al. 2007). Projections of increased winter precipitation and increases in the length and intensity of the summer drought season in the Pacific Northwest suggest that the study area will continue on this climate trajectory (Salathé et al. 2008; Spies et al. 2010). Uncertainty in future climate projections and subsequent impacts and feedback mechanisms in local ecosystems challenge current management practises. The Dry South Coast Ecosystems Climate Change Project continues to provide a framework for quantifying and predicting the impacts of climate on an integrated suite of ecological processes and measures of community composition and structure. Ongoing studies are integrating modelling, quantitative field assessment, and experimental field manipulations in order to direct monitoring of climate-induced change more judiciously and guide forest ecosystem management under future climatic conditions.

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Decagon EC-5 soil moisture sensors (Figure 8b, c; Table A1) measure volumetric water content by determining the dielectric constant of the soil using capacitance and frequency domain technology (Decagon Devices 2009; Ventura et al. 2010). The EC-5 sensors are calibrated for mineral soils and measure a range of 0 – 100% volumetric water content within a 0.2 L soil volume of influence. The sampling depth (25 – 30 cm depth) targets the rooting zone of vegetation growing on the forested sites. The accuracy is rated at ± 3%.

TABLE A1 *Summary of microclimate sensors and their technical specifications for micro-meteorological stations within the Dry South Coast Ecosystems Climate Change Project*

Microclimate parameter	Manufacturer/ model	Accuracy	Output range	Temperature range
Soil moisture	Decagon EC-5	0.03 m^3/m^3 (±3%) in all soils; <8 ds/m	0 to saturation	-40–60°C
Temperature	Copper-Constantan thermocouple wire	±0.1°C	n/a	-270–400°C
	Thermochron iButton® (model DS1921G)	±1°C	-40–85°C	-30–70°C
Wind speed	HOBO® wind sensor	±0.5 m/s at >1m/s	0–54 m/s	-40–75°C
Precipitation	HOBO® rain	±1.0% at <20 mm/hr	0–12.7 cm/hr; maximum 4000 tips per logging interval	0–50°C
Solar radiation	HOBO® silicon pyranometer	±10 W/m^2 or ±5%, whichever is greatest in sunlight	0–1280 W/m^2	-40–75°C
Temperature	HOBO® temperature and RH sensor	0.2°C over 0–50°C	-40–75°C	-40–75°C
Relative humidity (RH)	HOBO® temperature and RH sensor	±2.5% from 10 to 90% RH	0–100% RH at -40–75°C	-40–75°C

The temperature sensors are type T thermocouple (copper-constantan, CuCn) and iButtons® (Table A1). The thermocouples deployed below the soil surface are covered with electrical heat shrink tubing to protect them from moisture and the soldered tips from abrasion/damage. The iButtons® are self-contained, single-channel data loggers with a built-in digital thermometer and real-time clock (Figure 8a) (Maxim Integrated Products 2011). The iButtons® record data within the same unit as the sensor, so they are dug up every 2 months to download with the other data loggers. A 30-cm hole is dug adjacent to the unit, data are downloaded, and then the unit is placed back into the soil profile with the least disturbance possible.

Additional microclimate measures on CDFmm and CWHxm mesic sites

On the CDFmm and CWHxm mesic study sites, a tripod was installed that was equipped with one of the following: an Onset HOBO® wind speed sensor (at 3.5 m), a HOBO® rain gauge sensor (at 3.0 m), a HOBO® temperature and relative humidity sensor (at 1.5 m), a HOBO® silicon pyranometer (solar radiation) sensor (at 1.0 m),

and a HOBO® U30 data logger. In 2013, equivalent microclimate stations were installed on the CDFmm–CWHxm transitional zonal study sites.

Relative humidity (RH) and air temperature measurements were combined in one sensor that was mounted in a radiation shield 1.5 m above the ground on the north side of the climate station tripod at each site. The HOBO® temperature and RH sensor is accurate to 0.2°C at temperatures ranging from 0 to 50°C and to ± 2.5% RH from 10 to 90% RH (Table A1).

Precipitation was measured with Onset HOBO® rain sensors (Table A1), which consisted of tipping bucket rain gauges mounted on the tripod 3 m above the soil surface on the north side of the tripod. The rain gauge has a funnel at the top that directs the precipitation onto a mechanism that teeters back and forth when full. Each tip records a specified amount (0.2 mm) of precipitation in millimetres (up to a maximum of 80 mm per 1-hour logging interval).

The rain gauge sensors are not heated; therefore, if temperatures drop below freezing, the precipitation in the bucket freezes. When air temperatures rise above freezing, the snow and ice in the bucket melt and the amount is measured, although any sub-zero precipitation introduces two sources of error. First, if the bucket fills with snow or ice, any subsequent precipitation runs off and the total amount is not measured. Second, the hourly and daily time stamps for precipitation events are not accurate because there is a time lag in the melting period that skews and attenuates the data.

Additional potential sources of error with the tipping bucket are caused by debris accumulation in the bucket and by wind and turbulence. Leaves and needles from the trees, as well as pollen and dust, can accumulate and block the funnel in the bucket. The equipment is routinely checked in conjunction with data downloads, and if possible, the sites are visited after storm events to maintain the equipment. Undercatch due to winds and turbulence is also an issue with the tipping buckets, although the impact in the forested sites is minimal.

The amount of subcanopy solar radiation was measured with a HOBO® silicon pyranometer sensor (Table A1) mounted 1.0 m above the soil surface on the south side of the tripod in order to monitor light availability to the understorey vegetation. The sensor has a 300 – 1 100 nm spectral range. These sensors are typically used in open sites but are suitable for measuring light and predicting soil warming and evaporation within the forest; however, they are not suitable for monitoring or sampling plant growth (photosynthetically active radiation sensors that have a narrower spectral range of 400 – 700 nm are used for such studies). Silicon photodiodes are used to measure radiation flux in terms of power per unit area (W/m²). Small measurement errors occur when the sensors are used in natural sunlight conditions, but reduced accuracy occurs when the sensors are deployed under a plant canopy (Onset 2009). The HOBO® silicon pyranometer sensors were located under the forest canopy, so the measures will be used to compare relative differences in subcanopy radiation among sites.

Wind speed was measured 3.3 m above the soil surface on the south side of the tripod at each site. The HOBO® wind sensors (Table A1) are anemometers that measure wind speed every 3 seconds, and the hourly average is recorded on the (1-hour) logging interval. The HOBO® wind sensor is accurate within ± 0.5 m/s and measures wind speed up to 54 m/s.

Data loggers

The CS CR10 data loggers were housed in a water-resistant plastic box on the ground surface next to subplot 3 on each study site (Figures 9b, c). Each CS CR10 data logger was powered by a 12-V Panasonic rechargeable sealed lead-acid battery. The HOBO® data loggers were housed in a waterproof box mounted on the tripod at 1.8 m above the ground surface. They were powered by a 4 V rechargeable sealed lead-acid battery that was charged on site with a solar panel mounted on the south side of the tripod approximately 2 m above the soil surface.

Data loggers were downloaded bi-monthly. Data quality was assessed by comparing data from the different data loggers (Campbell Scientific CR10, HOBO U30, and iButton) and to other climate station data collected in the study area by the British Columbia Ministry of Forests, Lands and Natural Resource Operations, and Environment Canada. The data files were inspected for missing values and for malfunctioning sensors (e.g., extreme high and low values or "-6999" values) after each download.